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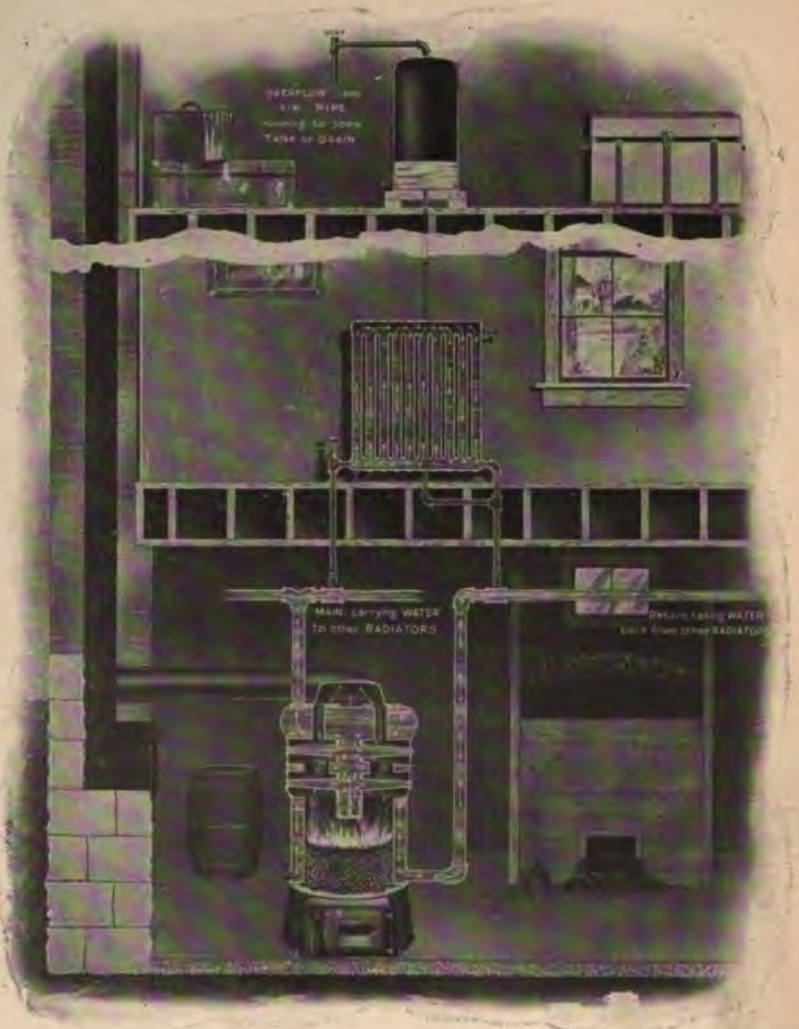
VENT
OVERFLOW and AIR PIPE running to some Tank or Drain
MAIN, carrying WATER to other RADIATORS
Return taking WATER back from other RADIATO

PRINCIPLE OF HOT WATER HEATING ILLUSTRATED BY TRANSVERSE SECTIONAL VIEW SHOWING BOILER, RADIATOR AND EXPANSION TANK.
American Radiator Company.

Heating and Ventilation

A Working Manual of

APPROVED PRACTICE IN THE HEATING AND VENTILATING OF DWELLING-HOUSES AND OTHER BUILDINGS, WITH COMPLETE PRACTICAL INSTRUCTION IN THE MECHANICAL DETAILS, OPERATION, AND CARE OF MODERN HEATING AND VENTILATING PLANTS

By CHARLES L. HUBBARD, S. B., M. E.
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Foreword

In recent years, such marvelous advances have been made in the engineering and scientific fields, and so rapid has been the evolution of mechanical and constructive processes and methods, that a distinct need has been created for a series of *practical working guides*, of convenient size and low cost, embodying the accumulated results of experience and the most approved modern practice along a great variety of lines. To fill this acknowledged need, is the special purpose of the series of handbooks to which this volume belongs.

❡ In the preparation of this series, it has been the aim of the publishers to lay special stress on the *practical* side of each subject, as distinguished from mere theoretical or academic discussion. Each volume is written by a well-known expert of acknowledged authority in his special line, and is based on a most careful study of practical needs and up-to-date methods as developed under the conditions of actual practice in the field, the shop, the mill, the power house, the drafting room, the engine room, etc.

❡ These volumes are especially adapted for purposes of self-instruction and home study. The utmost care has been used to bring the treatment of each subject within the range of the common understanding, so that the work will appeal not only to the technically trained expert, but also to the beginner and the self-taught practical man who wishes to keep abreast of modern progress. The language is simple and clear; heavy technical terms and the formulæ of the higher mathematics have been avoided, yet without sacrificing any of the requirements of practical instruction; the arrangement of matter is such as to carry the reader along by easy steps to complete mastery of each subject; frequent examples for practice are given, to enable the reader to test his knowledge and make it a permanent possession; and the illustrations are selected with the greatest care to supplement and make clear the references in the text.

¶ The method adopted in the preparation of these volumes is that which the American School of Correspondence has developed and employed so successfully for many years. It is not an experiment, but has stood the severest of all tests—that of practical use—which has demonstrated it to be the best method yet devised for the education of the busy working man.

¶ For purposes of ready reference and timely information when needed, it is believed that this series of handbooks will be found to meet every requirement.

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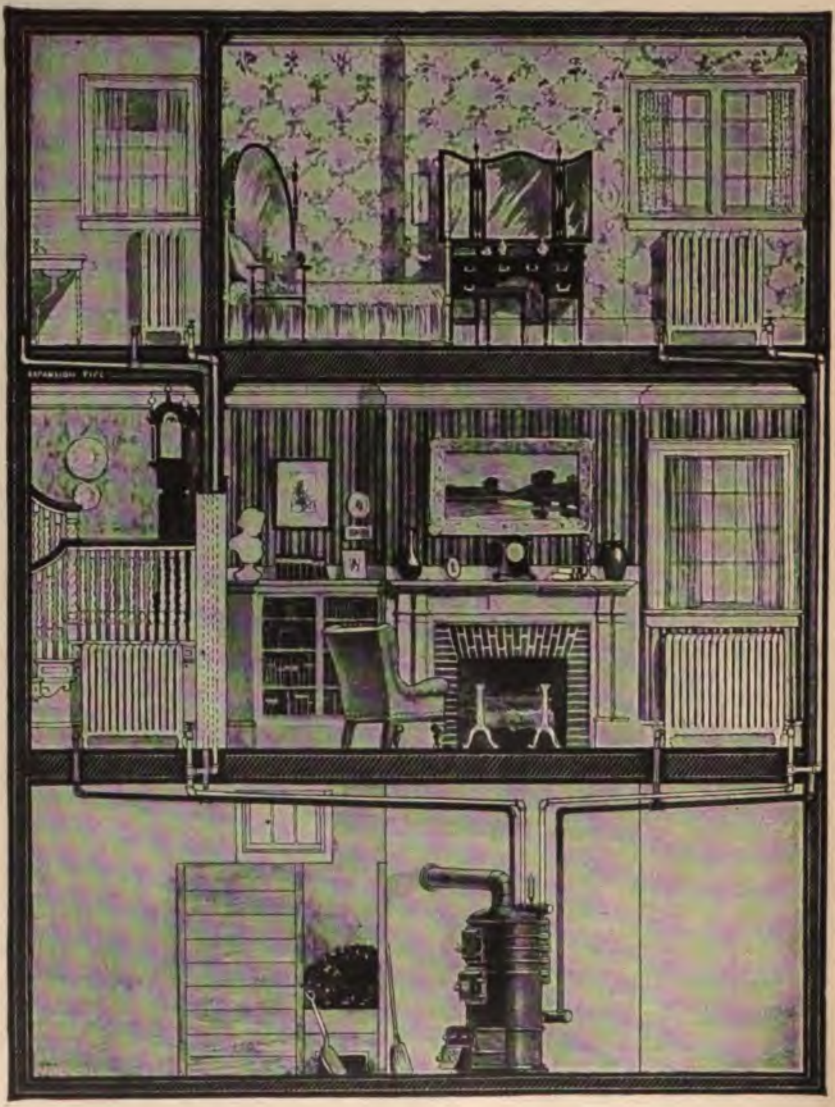


HOT WATER HEATER AND CONNECTIONS.

HEATING AND VENTILATION

PART I

SYSTEMS OF WARMING

Any system of warming must include, *first,* the combustion of fuel, which may take place in a fireplace, stove, or furnace, or a steam, or hot-water boiler; *second,* a system of transmission, by means of which the heat may be carried, with as little loss as possible, to the place where it is to be used for warming; and *third,* a system of diffusion, which will convey the heat to the air in a room, and to its walls, floors, etc., in the most economical way.

Stoves. The simplest and cheapest form of heating is the stove. The heat is diffused by radiation and convection directly to the objects and air in the room, and no special system of transmission is required. The stove is used largely in the country, and is especially adapted to the warming of small dwelling-houses and isolated rooms.

Furnaces. Next in cost of installation and in simplicity of operation, is the hot-air furnace. In this method, the air is drawn over heated surfaces and then transmitted through pipes, while at a high temperature, to the rooms where heat is required. Furnaces are used largely for warming dwelling-houses, also churches, halls, and schoolhouses of small size. They are more costly than stoves, but have certain advantages over that form of heating. They require less care, as several rooms may be warmed from a single furnace; and, being placed in the basement, more space is available in the rooms above, and the dirt and litter connected with the care of a stove are largely done away with. They require less care, as only one fire is necessary to warm all the rooms in a house of ordinary size. One great advantage in the furnace method of warming comes from the constant supply of fresh air which is required to bring the heat into the rooms. While this is greatly to be desired from a sanitary standpoint, it calls for the consumption of a larger amount of fuel than would otherwise be necessary. This is true because heat is required to warm the fresh air from out of doors up to the temperature of the rooms, in addition to replacing the heat lost by leakage and conduction through walls and windows.

A more even temperature may be maintained with a furnace than by the use of stoves, owing to the greater depth and size of the fire, which allows it to be more easily controlled.

When a building is placed in an exposed location, there is often difficulty in warming rooms on the north and west sides, or on that side toward the prevailing winds. This may be overcome to some extent by a proper location of the furnace and by the use of extra large pipes for conveying the hot air to those rooms requiring special attention.

Direct Steam. Direct steam, so called, is widely used in all classes of buildings, both by itself and in combination with other systems. The first cost of installation is greater than for a furnace; but the amount of fuel required is less, as no outside air supply is necessary. If used for warming hospitals, schoolhouses, or other buildings where a generous supply of fresh air is desired, this method must be supplemented by some form of ventilating system.

One of the principal advantages of direct steam is the ability to heat all rooms alike, regardless of their location or of the action of winds.

When compared with hot-water heating, it has still another desirable feature—which is its freedom from damage by the freezing of water in the radiators when closed, which is likely to happen in unused rooms during very cold weather in the case of the former system.

On the other hand, the sizes of the radiators must be proportioned for warming the rooms in the coldest weather, and unfortunately there is no satisfactory method of regulating the amount of heat in mild weather, except by shutting off or turning on steam in the radiators at more or less frequent intervals as may be required, unless one of the expensive systems of automatic control is employed. In large rooms, a certain amount of regulation can be secured by dividing the radiation into two or more parts, so that different combinations may be used under varying conditions of outside temperature. If two radiators are used, their surface should be proportioned, when convenient, in the ratio of 1 to 2, in which case one-third, two-thirds, or the whole power of the radiation can be used as desired.

Indirect Steam. This system of heating combines some of the advantages of both the furnace and direct steam, but is more costly to install than either of these. The amount of fuel required is about the same as for furnace heating, because in each case the cool fresh air must be warmed up to the temperature of the room, before it can become a medium for conveying heat to offset that lost by leakage and conduction through walls and windows.

A system for indirect steam may be so designed that it will supply a greater quantity of fresh air than the ordinary form of furnace, in which case the cost of fuel will of course be increased in proportion to the volume of air supplied. Instead of placing the radiators in the rooms, a special form of heater is supported near the basement ceiling and encased in either galvanized iron or brick. A cold-air supply duct is connected with the space below the heater, and warm air pipes are taken from the top and connected with registers in the rooms to be heated the same as in the case of furnace heating.

A separate stack or heater may be provided for each register if the rooms are large; but, if small and so located that they may be reached by short runs of horizontal pipe, a single heater may serve for two or more rooms.

The advantage of indirect steam over furnace heating comes from the fact that the stacks may be placed at or near the bases of the flues leading to the different rooms, thus doing away with long, horizontal runs of pipe, and counteracting to a considerable extent the effect of wind pressure upon exposed rooms. Indirect and direct heating are often combined to advantage by using the former for the more important rooms, where ventilation is desired, and the latter for rooms more remote or where heat only is required.

Another advantage is the large ratio between the radiating surface and grate-area, as compared with a furnace; this results in a large volume of air being warmed to a moderate temperature instead of a smaller quantity being heated to a much higher temperature, thus giving a more agreeable quality to the air and rendering it less dry.

Indirect steam is adapted to all the buildings mentioned in connection with furnace heating, and may be used to much better advantage in those of large size. This applies especially to cases where more than one furnace is necessary; for, with steam heat, a single boiler, or a battery of boilers, may be made to supply heat for a building of any size, or for a group of several buildings, if desired, and is much easier to care for than several furnaces widely scattered.

Direct-Indirect Radiators. These radiators are placed in the room the same as the ordinary direct type. The construction is such that when the sections are in place, small flues are formed between them; and air, being admitted through an opening in the outside wall, passes upward through them and becomes heated before entering the room. A switch damper is placed in the casing at the base of the radiator, so that air may be taken from the room itself instead of from out of doors, if so desired. Radiators of this kind are not used to any great extent, as there is likely to be more or less leakage of cold air into the room around the base. If ventilation is required, it is better to use the regular form of indirect heater with flue and register, if possible. It is sometimes desirable to partially ventilate an isolated room where it would be impossible to run a flue, and in cases of this kind the direct-indirect form is often useful.

Direct Hot Water. Hot water is especially adapted to the warming of dwellings and greenhouses, owing to the ease with which the temperature can be regulated. When steam is used, the radiators are always at practically the same temperature, while with hot water the temperature can be varied at will. A system for hot-water heating costs more to install than one for steam, as the radiators must be larger and the pipes more carefully run. On the other hand, the cost of operating is somewhat less, because the water need be carried only at a temperature sufficiently high to warm the rooms properly in mild weather, while with steam the building is likely to become overheated, and more or less heat wasted through open doors and windows.

A comparison of the relative costs of installing and operating hot-air, steam, and hot-water systems, is given in Table I.

TABLE I

Relative Cost of Heating Systems

	Hot Air	Steam	Hot Water
Relative cost of apparatus	9	13	15
Relative cost, adding repairs and fuel for five years	29½	29¾	27
Relative cost, adding repairs and fuel for fifteen years	81	63	52½

One disadvantage in the use of hot water is the danger from freezing when radiators are shut off in unused rooms. This makes it necessary in very cold weather to have all parts of the system turned on sufficiently to produce a circulation, even if very slow. This is sometimes accomplished by drilling a very small hole (about $\frac{1}{8}$ inch) in the valve-seat, to that when closed there will still be a very slow circulation through the radiator, thus preventing the temperature of the water from reaching the freezing point.

Indirect Hot Water. This is used under the same conditions as indirect steam, but more especially in the case of dwellings and hospitals. When applied to other and larger buildings, it is customary to force the water through the mains by means of a pump. Larger heating stacks and supply pipes are required than for steam; but the arrangement and size of air-flues and registers are practically the same, although they are sometimes made slightly larger in special cases.

Exhaust Steam. Exhaust steam is used for heating in connection with power plants, as in shops and factories, or in office buildings which have their own lighting plants. There are two methods of using exhaust steam for heating purposes. One is to carry a back pressure of 2 to 5 pounds on the engines, depending upon the length and size of the pipe mains; and the other is to use some form of *vacuum system* attached to the returns or air-valves, which tends to reduce the back pressure rather than to increase it.

Where the first method is used and a back pressure carried, either the boiler pressure or the cut-off of the engines must be increased, to keep the mean effective pressure the same and not reduce the horse-power delivered. In general it is more economical to utilize the exhaust steam for heating. There are instances, however, where the relation between the quantities of steam required for heating and for power are such—especially if the engines are run condensing—that it is better to throw the exhaust away and heat with live steam. Where the vacuum method is used, these difficulties are avoided; and for this reason that method is coming into quite common use. If the condensation from the exhaust steam is returned to the boilers, the oil must first be removed; this is usually accomplished by passing the steam through some form of grease extractor as it leaves the engine. The water of condensation is often passed through a separating tank in addition to this, before it is delivered to the return pumps. It is better, however, to remove a portion of the oil before the steam enters the heating system; otherwise a coating will be formed upon the inner surfaces of the radiators, which will reduce their efficiency to some extent.

Forced Blast. This method of heating, in different forms, is used for the warming of factories, schools, churches, theaters, halls—in fact, any large building where good ventilation is desired. The air for warming is drawn or forced through a heater of special design, and discharged by a fan or blower into ducts which lead to registers placed in the rooms to be warmed. The heater is usually made up in sections, so that steam may be admitted to or shut off from any section independently of the others, and the temperature of the air regulated in this manner. Sometimes a *by-pass damper* is attached, so that part of the air will pass through the heater and part around or over it; in this way the proportions of cold and heated air may be so adjusted as to give the desired temperature to the air entering the rooms. These forms of regulation are common where a blower is used for warming a single room, as in the case of a church or hall; but where several rooms are warmed, as in a schoolhouse. it is customary to use the main or primary heater at the blower for warming the air to a given temperature (somewhat below that which is actually required), and to supplement this by placing secondary coils or heaters at the bottoms of the flues leading to the different rooms. By means of this arrangement, the temperature of each room can be regulated independently of the others. The so-called *double-duct* system is sometimes employed. In this case, two ducts are carried to each register, one supplying hot air and the other cold or tempered air; and a damper for mixing these in the right proportions is placed in the flue, below the register.

Electric Heating. Unless electricity can be produced at a very low cost, it is not practicable for heating residences or large buildings. The electric heater, however, has quite a wide field of application in heating small offices, bathrooms, electric cars, etc. It is a convenient method of warming isolated rooms on cold mornings, in late spring and early fall, when the regular heating apparatus of the building is not in operation. It has the advantage of being instantly available, and the amount of heat can be regulated at will. Electric heaters are clean, do not vitiate the air, and are easily moved from place to place.

PRINCIPLES OF VENTILATION

Closely connected with the subject of heating is the problem of maintaining air of a certain standard of purity in the various buildings occupied.

The introduction of pure air can be done properly only in connection with some system of heating; and no system of heating is complete without a supply of pure air, depending in amount upon the kind of building and the purpose for which it is used.

Composition of the Atmosphere. Atmospheric air is not a simple substance but a mechanical mixture. Oxygen and nitrogen, the principal constituents, are present in very nearly the proportion of one part of oxygen to four parts of nitrogen by weight. Carbonic acid gas, the product of all combustion, exists in the proportion of 3 to 5 parts in 10,000 in the open country. Water in the form of vapor, varies greatly with the temperature and with the exposure of the air to open bodies of water. In addition to the above, there are generally present, in variable but exceedingly small quantities, ammonia, sulphuretted hydrogen, sulphuric, sulphurous, nitric, and nitrous acids, floating organic and inorganic matter, and local impurities. Air also contains ozone, which is a peculiarly active form of oxygen; and lately another constituent called *argon* has been discovered.

Oxygen is the most important element of the air, so far as both heating and ventilation are concerned. It is the active element in the chemical process of combustion and also in the somewhat similar process which takes place in the respiration of human beings. Taken into the lungs, it acts upon the excess of carbon in the blood, and possibly upon other ingredients, forming chemical compounds which are thrown off in the act of respiration or breathing.

Nitrogen. The principal bulk of the atmosphere is nitrogen, which exists uniformly diffused with oxygen and carbonic acid gas. This element is practically inert in all processes of combustion or respiration. It is not affected in composition, either by passing through a furnace during combustion or through the lungs in the process of respiration. Its action is to render the oxygen less active, and to absorb some part of the heat produced by the process of oxidation.

Carbonic acid gas is of itself only a neutral constituent of the atmosphere, like nitrogen; and—contrary to the general impression—its presence in moderately large quantities (if uncombined with other substances) is neither disagreeable nor especially harmful. Its presence, however, in air provided for respiration, decreases the readiness with which the carbon of the blood unites with the oxygen of the air; and therefore, when present in sufficient quantity, it may cause indirectly, not only serious, but fatal results. The real harm of a vitiated atmosphere, however, is caused by the other constituent gases and by the minute organisms which are produced in the process of respiration. It is known that these other impurities exist in fixed proportion to the amount of carbonic acid present in an atmosphere vitiated by respiration. Therefore, as the relative proportion of carbonic acid can easily be determined by experiment, the fixing of a standard limit of the amount in which it may be allowed, also limits the amounts of other impurities which are found in combination with it.

When carbonic acid is present in excess of 10 parts in 10,000 parts of air, a feeling of weariness and stuffiness, generally accompanied by a headache, will be experienced; while with even 8 parts in 10,000 parts a room would be considered close. For general considerations of ventilation, the limit should be placed at 6 to 7 parts in 10,000, thus allowing an increase of 2 to 3 parts over that present in outdoor air, which may be considered to contain four parts in 10,000 under ordinary conditions.

Analysis of Air. An accurate qualitative and quantitative analysis of air samples can be made only by an experienced chemist. There are, however, several approximate methods for determining the amount of carbonic acid present, which are sufficiently exact for practical purposes. Among these the following is one of the simplest:

The necessary apparatus consists of six clean, dry, and tightly corked bottles, containing respectively 100, 200, 250, 300, 350, and 400 cubic centimeters, a glass tube containing exactly 15 cubic centimeters to a given mark, and a bottle of perfectly clear, fresh limewater. The bottles should be filled with the air to be examined by means of a hand-ball syringe. Add to the smallest bottle 15 cubic centimeters of the limewater, put in the cork, and shake well. If the limewater has a milky appearance, the amount of carbonic acid will be at least 16 parts in 10,000. If the contents of the bottle remain clear, treat the bottle of 200 cubic centimeters in the same manner; a milky appearance or turbidity in this would indicate 12 parts in 10,000. In a similar manner, turbidity in the 250 cubic centimeter bottle indicates

10 parts in 10,000; in the 300, 8 parts; in the 350, 7 parts; and in the 400, less than 6 parts. The ability to conduct more accurate analyses can be attained only by special study and a knowledge of chemical properties and of methods of investigation.

Another method similar to the above, makes use of a glass cylinder containing a given quantity of limewater and provided with a piston. A sample of the air to be tested is drawn into the cylinder by an upward movement of the piston. The cylinder is then thoroughly shaken, and if the limewater shows a milky appearance, it indicates a certain proportion of carbonic acid in the air. If the limewater remains clear, the air is forced out, and another cylinder full drawn in, the operation being repeated until the limewater becomes milky. The size of the cylinder and the quantity of limewater are so proportioned that a change in color at the first, second, third, etc., cylinder full of air indicates different proportions of carbonic acid. This test is really the same in principle as the one previously described; but the apparatus used is in more convenient form.

Air Required for Ventilation. The amount of air required to maintain any given standard of purity can very easily be determined, provided we know the amount of carbonic acid given off in the process of respiration. It has been found by experiment that the average production of carbonic acid by an adult at rest is about .6 cubic foot per hour. If we assume the proportion of this gas as 4 parts in 10,000 in the external air, and are to allow 6 parts in 10,000 in an occupied room, the gain will be 2 parts in 10,000; or, in other words, there will be $\frac{2}{10,000} = .0002$ cubic foot of carbonic acid mixed with each cubic foot of fresh air entering the room. Therefore, if one person gives off .6 cubic foot of carbonic acid per hour, it will require $.6 \div .0002 = 3,000$ cubic feet of air per hour per person to keep the air in the room at the standard of purity assumed—that is, 6 parts of carbonic acid in 10,000 of air.

Table II has been computed in this manner, and shows the amount of air which must be introduced for each person in order to maintain various standards of purity.

While this table gives the theoretical quantities of air required for different standards of purity, and may be used as a guide, it will be better in actual practice to use quantities which experience has shown to give good results in different types of buildings. In auditoriums where the cubic space per individual is large, and in which the atmosphere is thoroughly fresh before the rooms are occupied, and the occupancy is of only two or three hours' duration, the air-supply may be reduced somewhat from the figures given below.

TABLE II

Quantity of Air Required per Person

Standard Parts of Carbonic Acid in 10,000 of Air in Room	Cubic Feet of Air Required per Person	
	Per Minute	Per Hour
5	100	6,000
6	50	3,000
7	33	2,000
8	25	1,500
9	20	1,200
10	16	1,000

Table III represents good modern practice and may be used with satisfactory results:

TABLE III

Air Required for Ventilation of Various Classes of Buildings

Air-Supply per Occupant for	Cubic Feet per Minute	Cubic Feet per Hour
Hospitals	80 to 100	4, 800 to 6, 000
High Schools	50	3, 000
Grammar Schools	40	2, 400
Theaters and Assembly Halls	25	1, 500
Churches	20	1, 200

When possible, the air-supply to any given room should be based upon the number of occupants. It sometimes happens, however, that this information is not available, or the character of the room is such that the number of persons occupying it may vary, as in the case of public waiting rooms, toilet rooms, etc. In instances of this kind, the required air-volume may be based upon the number of changes per hour. In using this method, various considerations must be taken into account, such as the use of the room and its condition as to crowding, character of occupants, etc. In general, the following will be found satisfactory for average conditions:

TABLE IV

Number of Changes of Air Required in Various Rooms

Use of Room	Changes of Air per Hour
Public Waiting Room	4 to 5
Public Toilets	5 " 6
Coat and Locker Rooms	4 " 5
Museums	3 " 4
Offices, Public	4 " 5
Offices, Private	3 " 4
Public Dining Rooms	4 " 5
Living Rooms	3 " 4
Libraries, Public	4 " 5
Libraries, Private	3 " 4

Force for Moving Air. Air is moved for ventilating purposes in two ways: (1) by expansion due to heating; (2) by mechanical means. The effect of heat on the air is to increase its volume and therefore lessen its density or weight, so that it tends to rise and is replaced by the colder air below. The available force for moving air obtained in this way is very small, and is quite likely to be overcome by wind or external causes. It will be found in general that the heat used for producing velocity in this manner, when transformed into work in the steam engine, is greatly in excess of that required to produce the same effect by the use of a fan.

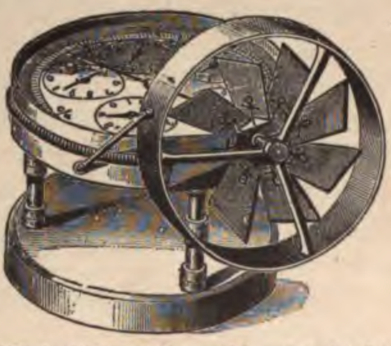


Fig. 1. Common Form of Anemometer, for Measuring Velocity of Air-Currents.

Ventilation by mechanical means is performed either by pressure or by suction. The former is used for delivering fresh air into a building, and the latter for removing the foul air from it. By both processes the air is moved without change in temperature, and the force for moving must be sufficient to overcome the effects of wind or changes in outside temperature. Some form of fan is used for this purpose.

Measurements of Velocity. The velocity of air in ventilating ducts and flues is measured directly by an instrument called an anemometer. A common form of this instrument is shown in Fig. 1. It consists of a series of flat vanes attached to an axis, and a series of dials.

The revolution of the axis causes motion of the hands in proportion to the velocity of the air, and the result can be read directly from the dials for any given period.

For approximate results the anemometer may be slowly moved across the opening in either vertical or horizontal parallel lines, so that the readings will be made up of velocities taken from all parts of the opening. For more accurate work, the opening should be divided into a number of squares by means of small twine, and readings taken at the center of each. The mean of these readings will give the average velocity of the air through the entire opening.

AIR DISTRIBUTION

The location of the air inlet to a room depends upon the size of the room and the purpose for which it is used. In the case of living rooms in dwelling-houses, the registers are placed either in the floor or in the wall near the floor; this brings the warm air in at the coldest part of the room and gives an opportunity for warming or drying the feet if desired. In the case of schoolrooms, where large volumes of warm air at moderate temperatures are required, it is best to discharge it through openings in the wall at a height of 7 or 8 feet from the floor; this gives a more even distribution, as the warmer air tends to rise and hence spreads uniformly under the ceiling; it then gradually displaces other air, and the room becomes filled with pure air without sensible currents or drafts. The cooler air sinks to the bottom of the room, and can be taken off through ventilating registers placed near the floor. The relative positions of the inlet and outlet are often governed to some extent by the building construction; but, if possible, they should both be located in the same side of the room. Figs. 2, 3, and 4 show common arrangements.

The vent outlet should always, if possible, be placed in an inside wall; otherwise it will become chilled and the air-flow through it will become sluggish. In theaters and churches which are closely packed, the air should enter at or near the floor, in finely-divided streams; and the discharge ventilation should be through openings in the ceiling. The reason for this is the large amount of animal heat given off from the bodies of the audience; this causes the air to become still further heated after entering the room, and the tendency is to rise continuously from floor to ceiling, thus carrying away all impurities from respiration as fast as they are given off.

All audience halls in which the occupants are closely seated should be treated in the same manner, when possible. This, however, cannot always be done, as the seats are often made removable so that the floor can be used for other purposes. In cases of this kind, part of the air may be introduced through floor registers placed along the outer aisles, and the remainder by means of wall inlets the same as for schoolrooms. The discharge ventilation should be partly through registers near the floor, supplemented by ample ceiling vents for use when the hall is crowded or the outside temperature high.

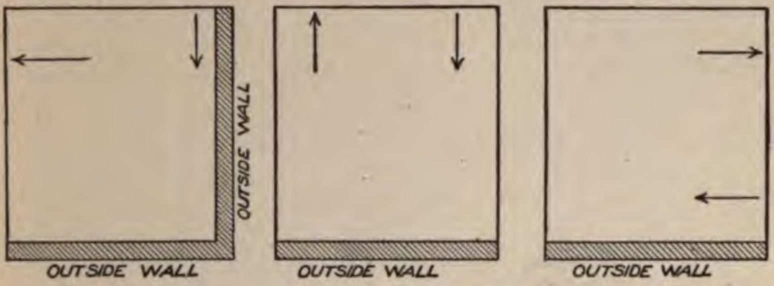


Fig. 2. Fig. 3. Fig. 4.

Diagrams Showing Relative Positions of Air Inlets and Outlets as Commonly Arranged.

The matter of air-velocities, size of flues, etc., will be taken up under the head of "Indirect Heating."

HEAT LOSS FROM BUILDINGS

A *British Thermal Unit*, or B. T. U., has been defined as the amount of heat required to raise the temperature of one pound of water one degree F. This measure of heat enters into many of the calculations involved in the solving of problems in heating and ventilation, and one should familiarize himself with the exact meaning of the term.

Causes of Heat Loss. The heat loss from a building is due to the following causes: (1) radiation and conduction of heat through walls and windows; (2) leakage of warm air around doors and windows and through the walls themselves; and (3) heat required to warm the air for ventilation.

Loss through Walls and Windows. The loss of heat through the walls of a building depends upon the material used in construction

TABLE V

Heat Losses in B. T. U. per Square Foot of Surface per Hour—Southern Exposure

Material	Difference between Inside and Outside Temperatures									
	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
8-in. Brick Wall	5	9	13	18	22	27	31	36	40	45
12-in. Brick Wall	4	7	10	13	16	20	23	26	30	33
16-in. Brick Wall	3	5	8	10	13	16	19	22	24	27
20-in. Brick Wall	2.8	4.5	7	9	11	14	16	18	20	23
24-in. Brick Wall	2.5	4	6	8	10	12	14	16	18	20
28-in. Brick Wall	2	3.5	5	7	9	11	13	14	16	18
32-in. Brick Wall	1.5	3	4.5	6	8	10	11	13	15	16
Single Window	12	24	36	49	60	73	85	93	110	122
Double Window	8	16	24	32	40	48	56	62	70	78
Single Skylight	11	21	31	42	52	63	73	84	94	104
Double Skylight	7	14	20	28	35	42	48	56	62	70
1-in. Wooden Door	4	8	12	16	20	24	28	32	36	40
2-in. Wooden Door	3	5	8	11	14	17	20	23	25	28
2-in. Solid Plaster Partition	6	12	18	24	30	36	42	48	54	60
3-in. Solid Plaster Partition	5	10	15	20	25	30	35	40	45	50
Concrete Floor on Brick Arch	2	4	6.5	9	11	13	15	18	20	22
Wood Floor on Brick Arch	1.5	3	4.5	6	7	9	10	12	13	15
Double Wood Floor	1	2	3	4	5	6	7	8	9	10
Walls of Ordinary Wooden Dwellings	3	5	8	10	13	16	19	22	24	27

For *solid stone walls*, multiply the figures for brick of the same thickness by 1.7. Where rooms have a *cold attic above or cellar beneath*, multiply the heat loss through walls and windows by 1.1.

Correction for Leakage. The figures given in the above table apply only to the most thorough construction. For the average well-built house, the results should be increased about 10 per cent; for fairly good construction, 20 per cent; and for poor construction, 30 per cent.

Table V applies only to a southern exposure; for other exposures multiply the heat loss given in Table V by the factors given in Table VI.

of the wall, the thickness, the number of layers, and the difference between the inside and outside temperatures. The exact amount of heat lost in this way is very difficult to determine theoretically, hence we depend principally on the results of experiments.

Loss by Air-Leakage. The leakage of air from a room varies from one to two or more changes of the entire contents per hour, depending upon the construction, opening of doors, etc. It is common practice to allow for one change per hour in well-constructed buildings where two walls of the room have an outside exposure. As the amount of leakage depends upon the extent of exposed wall and window surface, the simplest way of providing for this is to increase

TABLE VI

Factors for Calculating Heat Loss for Other than Southern Exposures

EXPOSURE	FACTOR
N.	1.32
E.	1.12
S.	1.0
W.	1.20
N. E.	1.22
N. W.	1.26
S. E.	1.06
S. W.	1.10
N., E., S., and W., or total exposure	1.16

the total loss through walls and windows by a factor depending upon the tightness of the building construction. Authorities differ considerably in the factors given for heat losses, and there are various methods for computing the same. The figures given in Table V have been used extensively in actual practice, and have been found to give good results when used with judgment. The table gives the heat losses through different thicknesses of walls, doors, windows, etc., in B. T. U., per square foot of surface per hour, for varying differences in inside and outside temperatures.

In computing the heat loss through walls, only those exposed to the outside air are considered.

In order to make the use of the table clear, we shall give a number of examples illustrating its use:

Example 1. Assuming an inside temperature of 70°, what will be the heat loss from a room having an exposed wall surface of 200 square feet and a glass surface of 50 square feet, when the outside temperature is zero? The wall is of brick, 16 inches in thickness, and has a southern exposure; the windows are single; and the construction is of the best, so that no account need be taken of leakage

We find from Table V, that the factor for a 16-inch brick wall with a difference in temperature of 70° is 19, and that for glass (single window) under the same condition is 85; therefore,

Loss through walls = 200 × 19 = 3,800
Loss through windows = 50 × 85 = 4,250

Total loss per hour = 8,050 B. T. U.

Example 2. A room 15 ft. square and 10 ft. high has two exposed walls, one toward the north, and the other toward the west. There are 4 windows, each 3 feet by 6 feet in size. The two in the north wall are double, while the

other two are single. The walls are of brick, 20 inches in thickness. With an inside temperature of 70°, what will be the heat loss per hour when it is 10° below zero?

Total exposed surface = 15 × 10 × 2 = 300
Glass surface = 3 × 6 × 4 = 72

Net wall surface = 228
Difference between inside and outside temperature 80°.
Factor for 20-inch brick wall is 18.
Factor for single window is 93.
Factor for double window is 62.
The heat losses are as follows:
Wall, 228 × 18 = 4,104
Single windows, 36 × 93 = 3,348
Double windows, 36 × 62 = 2,232

9,684 B. T. U.

As one side is toward the north, and the other toward the west, the actual exposure is N. W. Looking in Table VI, we find the correction factor for this exposure to be 1.26; therefore the total heat loss is

9,684 × 1.26 = 12,201.84 B. T. U.

Example 3. A dwelling-house of fair wooden construction measures 160 ft. around the outside; it has 2 stories, each 8 ft. in height; the windows are single, and the glass surface amounts to one-fifth the total exposure; the attic and cellar are unwarmed. If 8,000 B. T. U. are utilized from each pound of coal burned in the furnace, how many pounds will be required per hour to maintain a temperature of 70° when it is 20° above zero outside?

Total exposure = 160 × 16 = 2,560
Glass surface = 2,560 ÷ 5 = 512

Net wall = 2,048
Temperature difference = 70 − 20 = 50°
Wall 2,048 × 13 = 26,624
Glass 512 × 60 = 30,720

57,344 B. T. U.

As the building is exposed on all sides, the factor for exposure will be the average of those for N., E., S., and W., or

(1.32 + 1.12 + 1.0 + 1.20) ÷ 4 = 1 16

The house has a cold cellar and attic, so we must increase the heat loss

10 per cent for each of the first two conditions, and 20 per cent for the last. Making these corrections we have:

$$57{,}344 \times 1.16 \times 1.10 \times 1.10 \times 1.20 = 96{,}338 \text{ B. T. U.}$$

If one pound of coal furnishes 8,000 B. T. U., then 96,338 ÷ 8,000 = 12 pounds of coal per hour required to warm the building to 70° under the conditions stated.

Approximate Method. For dwelling-houses of the average construction, the following simple method for calculating the heat loss may be used. Multiply the total exposed surface by 45, which will give the heat loss in B. T. U. per hour for an inside temperature of 70° in zero weather.

This factor is obtained in the following manner: Assume the glass surface to be one-sixth the total exposure, which is an average proportion. Then each square foot of exposed surface consists one-sixth of glass and five-sixths of wall, and the heat loss for 70° difference in temperature would be as follows:

$$\text{Wall } \frac{5}{6} \times 19 = 15.8$$

$$\text{Glass } \frac{1}{6} \times 85 = \underline{14.1}$$

$$29.9$$

Increasing this 20 per cent for leakage, 16 per cent for exposure, and 10 per cent for cold ceilings, we have:

$$29.9 \times 1.20 \times 1.16 \times 1.10 = 45.$$

The loss through floors is considered as being offset by including the kitchen walls of a dwelling-house, which are warmed by the range, and which would not otherwise be included if computing the size of a furnace or boiler for heating.

If the heat loss is required for outside temperatures other than zero, multiply by 50 for 10 degrees below, and by 40 for 10 degrees above zero.

This method is convenient for approximations in the case of dwelling-houses; but the more exact method should be used for other types of buildings, and in all cases for computing the heating surface for separate rooms. *When calculating the heat loss from isolated rooms, the cold inside walls as well as the outside must be considered.*

The loss through a wall next to a cold attic or other unwarmed space may in general be taken as about two-thirds that of an outside wall.

Heat Loss by Ventilation. One B. T. U. will raise the temperature of 1 cubic foot of air 55 degrees at average temperatures and pressures, or will raise 55 cubic feet 1 degree, so that the heat required for the ventilation of any room can be found by the following formula:

$$\frac{\text{Cu. ft. of air per hour} \times \text{Number of degrees rise}}{55} = \text{B. T. U. required.}$$

To compute the heat loss for any given room which is to be ventilated, first find the loss through walls and windows, and correct for exposure and leakage; then compute the amount required for ventilation as above, and take the sum of the two. An inside temperature of 70° is always assumed unless otherwise stated.

Examples. What quantity of heat will be required to warm 100,000 cubic feet of air to 70° for ventilating purposes when the outside temperature is 10 below zero?

$$100{,}000 \times 80 \div 55 = 145{,}454 \text{ B. T. U.}$$

How many B. T. U. will be required per hour for the ventilation of a church seating 500 people, in zero weather?

Referring to Table III, we find that the total air required per hour is 1,200 × 500 = 600,000 cu. ft.; therefore 600,000 × 70 ÷ 55 = 763,636 B. T. U.

The factor $\frac{\text{Rise in Temperature}}{55}$ is approximately 1.1 for 60°, 1.3 for 70°, and 1.5 for 80°. Assuming a temperature of 70° for the entering air, we may multiply the air-volume supplied for ventilation by 1.1 for an outside temperature of 10° above 0, by 1.3 for zero, and by 1.5 for 10° below zero—which covers the conditions most commonly met with in practice.

EXAMPLES FOR PRACTICE

1. A room in a grammar school 28 ft. by 32 ft. and 12 feet high is to accommodate 50 pupils. The walls are of brick 16 inches in thickness; and there are 6 single windows in the room, each 3 ft. by 6 ft.; there are warm rooms above and below; the exposure is S. E. How many B. T. U. will be required per hour for warming the room, and how many for ventilation, in zero weather, assuming the building to be of average construction?

ANS. 24,261 + for warming; 152,727 + for ventilation.

2. A stone church seating 400 people has walls 20 inches in thickness. It has a wall exposure of 5,000 square feet, a glass expos-

ure (single windows) of 600 square feet, and a roof exposure of 7,000 square feet; the roof is of 2-inch pine plank, and the factor for heat loss may be taken the same as for a 2-inch wooden door. The floor is of wood on brick arches, and has an area of 4,000 square feet. The building is exposed on all sides, and is of first-class construction. What will be the heat required per hour for both warming and ventilation when the outside temperature is 20° above zero?

ANS. 296,380 for warming; 436,363 + for ventilation.

3. A dwelling-house of average wooden construction measures 200 feet around the outside, and has 3 stories, each 9 feet high. Compute the heat loss by the approximate method when the temperature is 10° below zero.

ANS. 270,000 B. T. U. per hour.

FURNACE HEATING

In construction, a furnace is a large stove with a combustion chamber of ample size over the fire, the whole being inclosed in a casing of sheet iron or brick. The bottom of the casing is provided with a cold-air inlet, and at the top are pipes which connect with registers placed in the various rooms to be heated. Cold, fresh air is brought from out of doors through a pipe or duct called the *cold-air box;* this air enters the space between the casing and the furnace near the bottom, and, in passing over the hot surfaces of the fire-pot and combustion chamber, becomes heated. It then rises through the warm-air pipes at the top of the casing, and is discharged through the registers into the rooms above.

As the warm air is taken from the top of the furnace, cold air flows in through the cold-air box to take its place. The air for heating the rooms does not enter the combustion chamber.

Fig. 5 shows the general arrangement of a furnace with its connecting pipes. The cold-air inlet is seen at the bottom, and the hot-air pipes at the top; these are all provided with dampers for shutting off or regulating the amount of air flowing through them. The feed or fire door is shown at the front, and the ash door beneath it; a *water-pan* is placed inside the casing, and furnishes moisture to the warm air before passing into the rooms; water is either poured into the pan through an opening in the front, provided for this purpose, or is supplied automatically through a pipe.

The fire is regulated by means of a draft slide in the ash door, and a cold-air or regulating damper placed in the smoke-pipe. Clean-out doors are placed at different points in the casing for the removal of ashes and soot. Furnaces are made either of cast iron, or of wrought-iron plates riveted together and provided with brick-lined firepots.

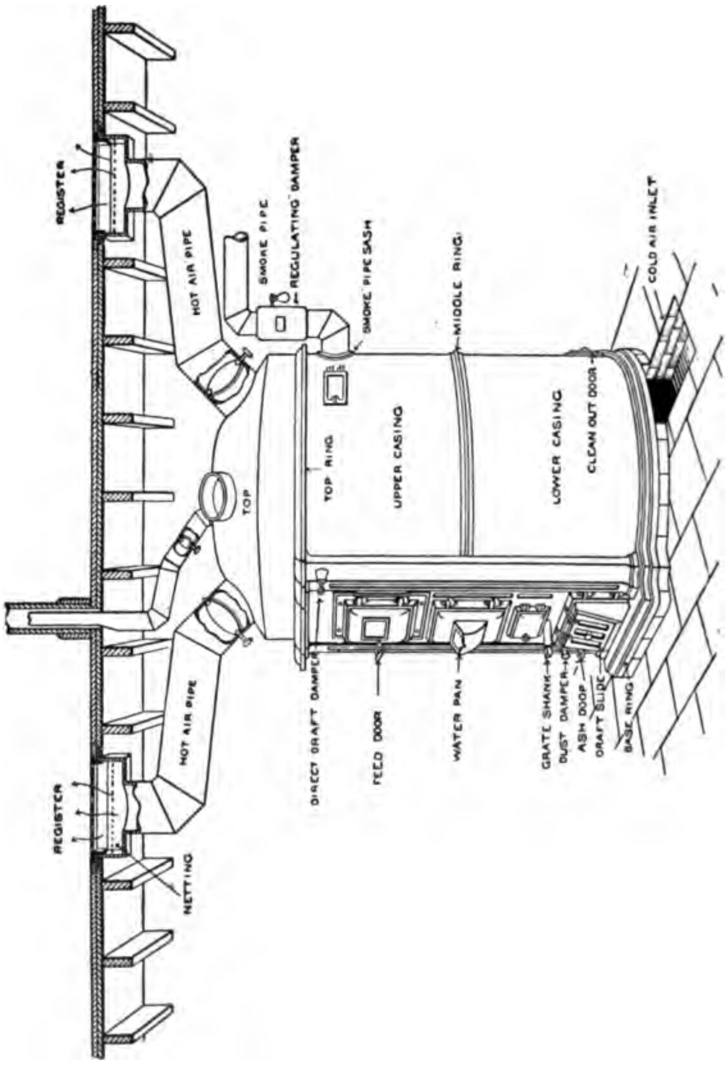


Fig. 5. General Arrangement of Details of a Hot-Air Furnace, with Connecting Pipes.

Types of Furnaces. Furnaces may be divided into two general types known as *direct-draft* and *indirect-draft*. Fig. 6 shows a common form of *direct-draft* furnace with a brick setting; the better class have a radiator, generally placed at the top, through which the gases pass before reaching the smoke-pipe. They have but one damper, usually combined with a cold-air check. Many of the cheaper direct-draft furnaces have no radiator at all, the gases passing directly into the smoke-pipe and carrying away much heat that should be utilized.

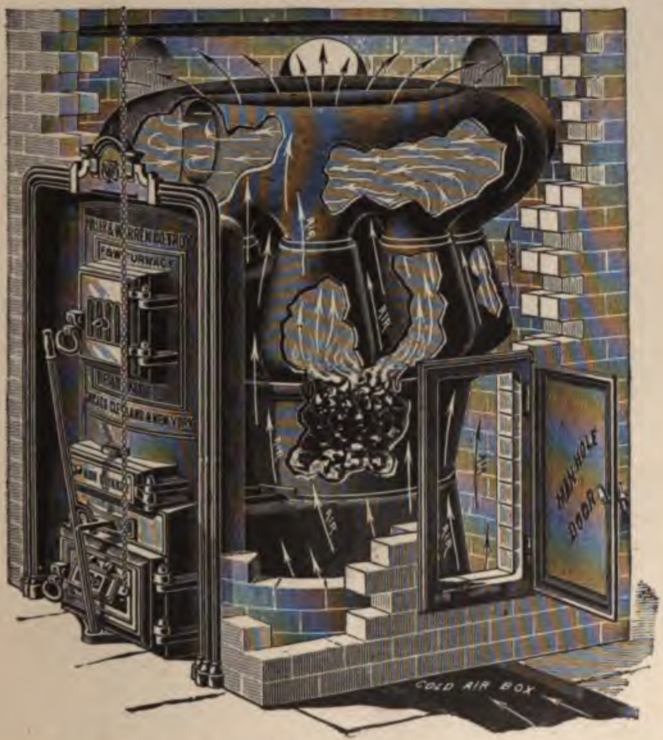


Fig. 6. A Common Type of Direct-Draft Furnace in Brick Setting. Cast-Iron Radiator at Top.

The furnace shown in Fig. 6 is made of cast iron and has a large radiator at the top; the smoke connection is shown at the rear.

Fig. 7 represents another form of direct-draft furnace. In this case the radiator is made of sheet-steel plates riveted together, and the outer casing is of heavy galvanized iron instead of brick.

In the ordinary *indirect-draft* type of furnace (see Fig. 8), the gases pass downward through flues to a radiator located near the base, thence upward through another flue to the smoke-pipe. In addition to the damper in the smoke-pipe, a direct-draft damper is required to give direct connection with the funnel when coal is first put on, to facilitate the escape of gas to the chimney. When the chimney draft is weak, trouble from gas is more likely to be experienced with furnaces of this type than with those having a direct draft.

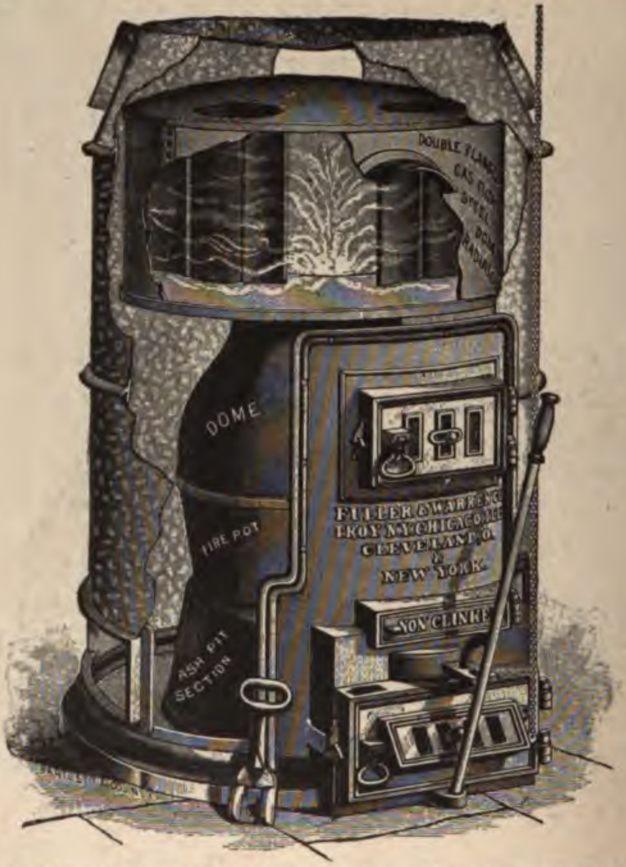
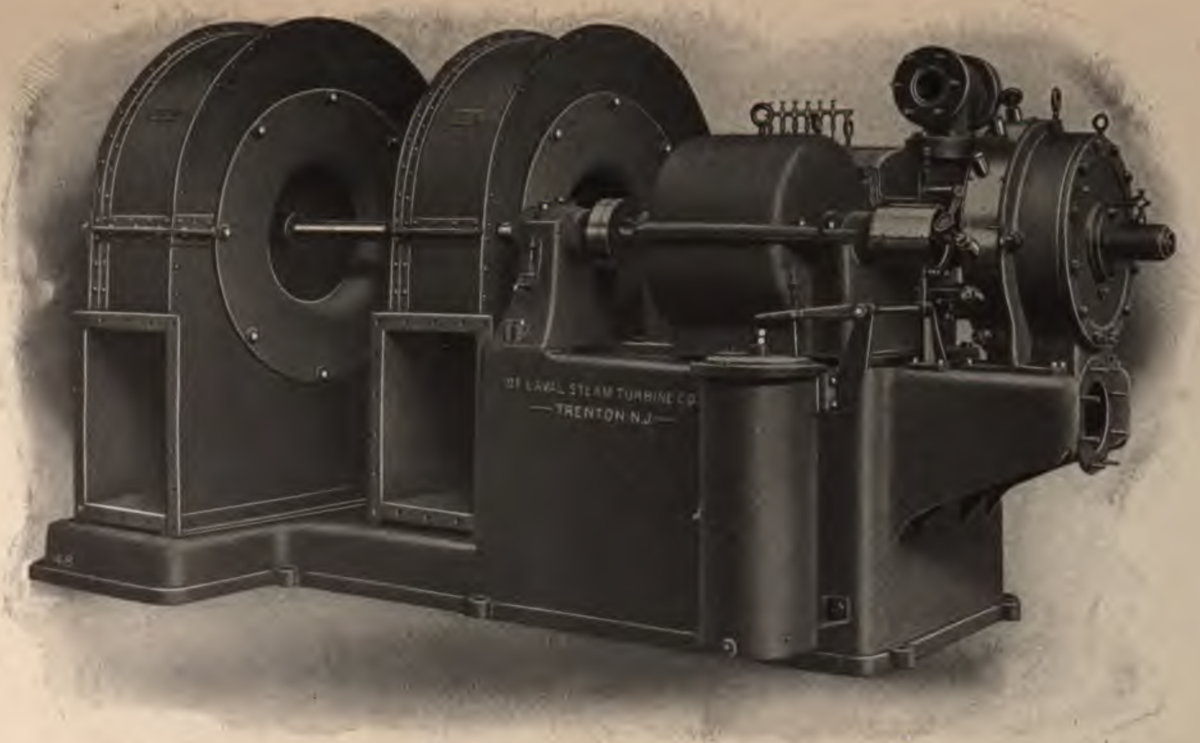


Fig. 7. Direct-Draft Furnace with Galvanized-Iron Casing. Radiator (at top) Made of Riveted Steel Plates.

Grates. No part of a furnace is of more importance than the grates. The plain grate rotating about a center pin was for a long time the one most commonly used. These grates were usually provided with a clinker door for removing any refuse too large to pass between the grate bars. The action of such grates tends to leave a



150 H.P. DE LAVAL TURBINE BLOWER.

cone of ashes in the center of the fire causing it to burn more freely around the edges. A better form of grate is the revolving triangular pattern, which is now used in many of the leading furnaces. It consists of a series of triangular bars having teeth. The bars are connected by gears, and are turned by means of a detachable lever. If properly used, this grate will cut a slice of ashes and clinkers from under the entire fire with little, if any loss of unconsumed coal.

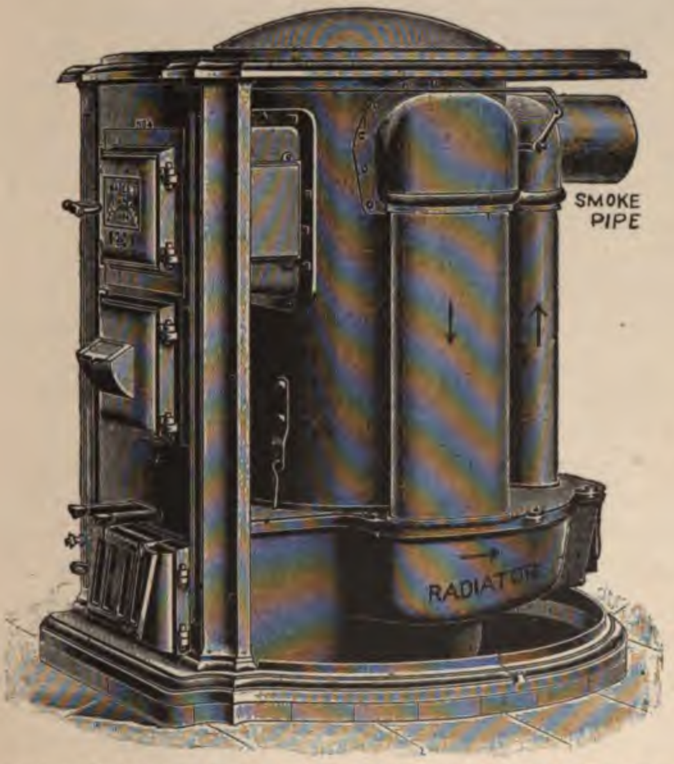


Fig. 8. Indirect-Draft Type of Furnace. Gases Pass Downward to Radiator at Bottom, Thence Upward to Smoke-Pipe.

The Firepot. Firepots are generally made of cast iron or of steel plate lined with firebrick. The depth ranges from about 12 to 18 inches. In cast-iron furnaces of the better class, the firepot is made very heavy, to insure durability and to render it less likely to become red-hot. The firepot is sometimes made in two pieces, to reduce the liability to cracking. The heating surface is sometimes increased by corrugations, pins, or ribs.

A firebrick lining is necessary in a wrought-iron or steel furnace to protect the thin shell from the intense heat of the fire. Since brick-lined firepots are much less effective than cast-iron in transmitting heat, such furnaces depend to a great extent for their efficiency on the heating surface in the dome and radiator; and this, as a rule, is much greater than in those of cast iron.

Cast-iron furnaces have the advantage when coal is first put on (and the drop flues and radiator are cut out by the direct damper) of still giving off heat from the firepot, while in the case of brick linings very little heat is given off in this way, and the rooms are likely to become somewhat cooled before the fresh coal becomes thoroughly ignited.

Combustion Chamber. The body of the furnace above the firepot, commonly called the *dome* or *feed section*, provides a combustion chamber. This chamber should be of sufficient size to permit the gases to become thoroughly mixed with the air passing up through the fire or entering through openings provided for the purpose in the feed door. In a well-designed furnace, this space should be somewhat larger than the firepot.

Radiator. The radiator, so called, with which all furnaces of the better class are provided, acts as a sort of reservoir in which the gases are kept in contact with the air passing over the furnace until they have parted with a considerable portion of their heat. Radiators are built of cast iron, of steel plate, or of a combination of the two. The former is more durable and can be made with fewer joints, but owing to the difficulty of casting radiators of large size, steel plate is commonly used for the sides.

The effectiveness of a radiator depends on its form, its heating surface, and the difference between the temperature of the gases and the surrounding air. Owing to the accumulation of soot, the bottom surface becomes practically worthless after the furnace has been in use a short time; surfaces, to be effective, must therefore be self-cleaning.

If the radiator is placed near the bottom of the furnace the gases are surrounded by air at the lowest temperature, which renders the radiator more effective for a given size than if placed near the top and surrounded by warm air. On the other hand, the cold air has a tendency to condense the gases, and the acids thus formed are likely to corrode the iron.

Heating Surface. The different heating surfaces may be described as follows: Firepot surface; surfaces acted upon by direct rays of heat from the fire, such as the dome or combustion chamber; gas- or smoke-heated surfaces, such as flues or radiators; and extended surfaces, such as pins or ribs. Surfaces unlike in character and location, vary greatly in heating power, so that, in making comparisons of different furnaces, we must know the kind, form, and location of the heating surfaces, as well as the area.

In some furnaces having an unusually large amount of surface, it will be found on inspection that a large part would soon become practically useless from the accumulation of soot. In others a large portion of the surface is lined with firebrick, or is so situated that the air-currents are not likely to strike it.

The ratio of grate to heating surface varies somewhat according to the size of furnace. It may be taken as 1 to 25 in the smaller sizes, and 1 to 15 in the larger.

Efficiency. One of the first items to be determined in estimating the heating capacity of a furnace, is its efficiency—that is, the proportion of the heat in the coal that may be utilized for warming. The efficiency depends chiefly on the area of the heating surface as compared with the grate, on its character and arrangement, and on the rate of combustion. The usual proportions between grate and heating surface have been stated. The rate of combustion required to maintain a temperature of 70° in the house, depends, of course, on the outside temperature. In very cold weather a rate of 4 to 5 pounds of coal per square foot of grate per hour must be maintained.

One pound of good anthracite coal will give off about 13,000 B. T. U., and a good furnace should utilize 70 per cent of this heat. The efficiency of an ordinary furnace is often much less, sometimes as low as 50 per cent.

In estimating the required size of a first-class furnace with good chimney draft, we may safely count upon a maximum combustion of 5 pounds of coal per square foot of grate per hour, and may assume that 8,000 B. T. U. will be utilized for warming purposes from each pound burned. This quantity corresponds to an efficiency of 60 per cent.

Heating Capacity. Having determined the heat loss from a building by the methods previously given, it is a simple matter to compute the size of grate necessary to burn a sufficient quantity of coal to furnish the amount of heat required for warming.

In computing the size of furnace, it is customary to consider the whole house as a single room, with four outside walls and a cold attic. The heat losses by conduction and leakage are computed, and increased 10 per cent for the cold attic, and 16 per cent for exposure. The heat delivered to the various rooms may be considered as being made up of two parts—*first*, that required to warm the outside air up to 70° (the temperature of the rooms); and *second*, the quantity which must be added to this to offset the loss by conduction and leakage. Air is usually delivered through the registers at a temperature of 120°, with zero conditions outside, in the best class of residence work; so that $\frac{70}{120}$ of the heat given to the entering air may be considered as making up the first part, mentioned above, leaving $\frac{50}{120}$ available for purely heating purposes. From this it is evident that the heat supplied to the entering air must be equal to $1 \div \frac{50}{120} = 2.4$ times that required to offset the loss by conduction and leakage.

Example. The loss through the walls and windows of a building is found to be 80,000 B. T. U. per hour in zero weather. What will be the size of furnace required to maintain an inside temperature of 70 degrees?

From the above, we have the total heat required, equal to 80,000 × 2.4 = 192,000 B. T. U. per hour. If we assume that 8,000 B. T. U. are utilized per pound of coal, then 192,000 ÷ 8,000 = 24 pounds of coal required per hour; and if 5 pounds can be burned on each square foot of grate per hour, then $\frac{24}{5} = 4.8$ square feet required. A grate 30 inches in diameter has an area of 4.9 square feet, and is the size we should use.

When the outside temperature is taken as 10° below zero, multiply by 2.6 instead of 2.4; and multiply by 2.8 for 20° below.

Table VII will be found useful in determining the diameter of firepot required.

TABLE VII

Firepot Dimensions

Average Diameter of Grate, in Inches	Area in Square Feet
18	1.77
20	2.18
22	2.64
24	3.14
26	3.69
28	4.27
30	4.91
32	5.58

EXAMPLES FOR PRACTICE

1. A brick apartment house is 20 feet wide, and has 4 stories, each being 10 feet in height. The house is one of a block, and is exposed only at the front and rear. The walls are 16 inches thick, and the block is so sheltered that no correction need be made for exposure. Single windows make up $\frac{1}{8}$ the total exposed surface. Figure for cold attic but warm basement. What area of grate surface will be required for a furnace to keep the house at a temperature of 70° when it is 10° below zero outside? Ans. 3.5 square feet.

2. A house having a furnace with a firepot 30 inches in diameter, is not sufficiently warmed, and it is decided to add a second furnace to be used in connection with the one already in. The heat loss from the building is found by computation to be 133,600 B. T. U. per hour, in zero weather. What diameter of firepot will be required for the extra furnace? Ans. 24 inches.

Location of Furnace. A furnace should be so placed that the warm-air pipes will be of nearly the same length. The air travels most readily through pipes leading toward the sheltered side of the house and to the upper rooms. Therefore pipes leading toward the north or west, or to rooms on the first floor, should be favored in regard to length and size. The furnace should be placed somewhat to the north or west of the center of the house, or toward the points of compass from which the prevailing winds blow.

Smoke-Pipes. Furnace smoke-pipes range in size from about 6 inches in the smaller sizes to 8 or 9 inches in the larger ones. They are generally made of galvanized iron of No. 24 gauge or heavier. The pipe should be carried to the chimney as directly as possible, avoiding bends which increase the resistance and diminish the draft. Where a smoke-pipe passes through a partition, it should be protected by a soapstone or double-perforated metal collar having a diameter at least 8 inches greater than that of the pipe. The top of the smoke-pipe should not be placed within 8 inches of unprotected beams, nor less than 6 inches under beams protected by asbestos or plaster with a metal shield beneath. A collar to make tight connection with the chimney should be riveted to the pipe about 5 inches from the end, to prevent the pipe being pushed too far into the flue. Where the pipe is of unusual length, it is well to cover it to prevent loss of heat and the condensation of smoke.

Chimney Flues. Chimney flues, if built of brick, should have walls 8 inches in thickness, unless terra-cotta linings are used, when only 4 inches of brickwork is required. Except in small houses where an 8 by 8-inch flue may be used, the nominal size of the smoke flue should be at least 8 by 12-inches, to allow for contractions or offsets. A clean-out door should be placed at the bottom of the flue, for removing ashes and soot. A square flue cannot be reckoned at its full area, as the corners are of little value. To avoid down drafts, the top of the chimney must be carried above the highest point of the roof unless provided with a suitable hood or top.

Cold-Air Box. The cold-air box should be large enough to supply a volume of air sufficient to fill all the hot-air pipes at the same time. If the supply is too small, the distribution is sure to be unequal, and the cellar will become overheated from lack of air to carry away the heat generated.

If a box is made too small, or is throttled down so that the volume of air entering the furnace is not large enough to fill all the pipes, it will be found that those leading to the less exposed side of the house or to the upper rooms will take the entire supply, and that additional air to supply the deficiency will be drawn down through registers in rooms less favorably situated. It is common practice to make the area of the cold-air box three-fourths the combined area of the hot-air pipes. The inlet should be placed where the prevailing cold winds will blow into it; this is commonly on the north or west side of the house. If it is placed on the side away from the wind, warm air from the furnace is likely to be drawn out through the cold-air box.

Whatever may be the location of the entrance to the cold-air box, changes in the direction of the wind may take place which will bring the inlet on the wrong side of the house. To prevent the possibility of such changes affecting the action of the furnace, the cold-air box is sometimes extended through the house and left open at both ends, with check-dampers arranged to prevent back-drafts. These checks should be placed some distance from the entrance, to prevent their becoming clogged with snow or sleet.

The cold-air box is generally made of matched boards; but galvanized iron is much better; it costs more than wood, but is well worth the extra expense on account of tightness, which keeps the dust and ashes from being drawn into the furnace casing to be discharged through the registers into the rooms above.

The cold-air inlet should be covered with galvanized wire netting with a mesh of at least three-eighths of an inch. The frame to which it is attached should not be smaller than the inside dimensions of the cold-air box. A door to admit air from the cellar to the cold-air box is generally provided. As a rule, air should be taken from this source, only when the house is temporarily unoccupied or during high winds.

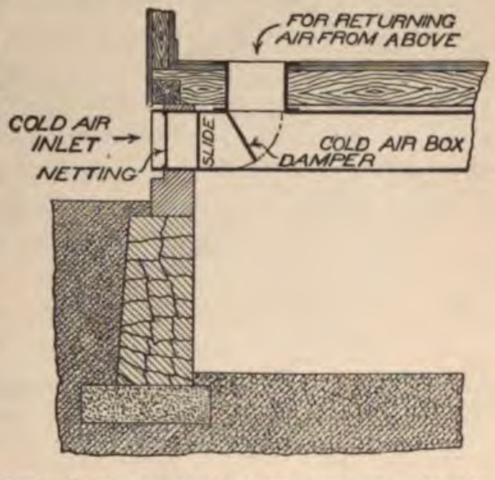


Fig 9. Common Method of Connecting Return Duct to Cold-Air Box.

Return Duct. In some cases it is desirable to return air to the furnace from the rooms above, to be reheated. Ducts for this purpose are common in places where the winter temperature is frequently below zero. Return ducts when used, should be in addition to the regular cold-air box. Fig. 9 shows a common method of making the connection between the two. By proper adjustment of the swinging damper, the air can be taken either from out of doors or through the register from the room above. The return register is often placed in the hallway of a house, so that it will take the cold air which rushes in when the door is opened and also that which may leak in around it while closed. Check-valves or flaps of light gossamer or woolen cloth should be placed between the cold-air box and the registers to prevent back-drafts during winds.

The return duct should not be used too freely at the expense of outdoor air, and its use is not recommended except during the night when air is admitted to the sleeping rooms through open windows.

Warm-Air Pipes. The required size of the warm-air pipe to any given room, depends on the heat loss from the room and on the volume of warm air required to offset this loss. Each cubic foot of air warmed from zero to 120 degrees brings into a room 2.2 B. T. U. We have already seen that in zero weather, with the air entering the registers at 120 degrees, only $\frac{50}{120}$ of the heat contained in the air is available for offsetting the losses by radiation and conduction, so that only $2.2 \times \frac{50}{120} = .9$ B. T. U. in each cubic foot of entering air can be utilized for warming purposes. Therefore, if we divide the computed heat loss in B. T. U. from a room, by .9, it will give the number of cubic feet of air at 120 degrees necessary to warm the room in zero weather.

As the outside temperature becomes colder, the quantity of heat brought in per cubic foot of air increases; but the proportion available for warming purposes becomes less at nearly the same rate, so

TABLE VIII
Warm-Air Pipe Dimensions

Diameter of Pipe, in Inches	Area in Square Inches	Area in Square Feet
6	28	.196
7	38	.267
8	50	.349
9	64	.442
10	79	.545
11	95	.660
12	113	.785
13	133	.922
14	154	1.07
15	177	1.23
16	201	1.40

that for all practical purposes we may use the figure .9 for all usual conditions. In calculating the size of pipe required, we may assume maximum velocities of 260 and 380 feet per minute for rooms on the first and second floors respectively. Knowing the number of cubic feet of air per minute to be delivered, we can divide it by the velocity, which will give us the required area of the pipe in square feet.

Round pipes of tin or galvanized iron are used for this purpose. Table VIII will be found useful in determining the required diameters of pipe in inches.

Example. The heat loss from a room on the second floor is 18,000 B. T. U. per hour. What diameter of warm-air pipe will be required?

18,000 ÷ .9 = 20,000 = cubic feet of air required per hour. 20,000 ÷ 60 = 333 per minute. Assuming a velocity of 380 feet per minute, we have 333 ÷ 380 = .87 square foot, which is the area of pipe required. Referring to Table VIII, we find this comes between a 12-inch and a 13-inch pipe, and the larger size would probably be chosen.

EXAMPLES FOR PRACTICE

1. A first-floor room has a computed loss of 27,000 B. T. U. per hour when it is 10° below zero. The air for warming is to enter through two pipes of equal size, and at a temperature of 120 degrees. What will be the required diameter of the pipes?

Ans. 14 inches.

2. If in the above example the room had been on the second floor, and the air was to be delivered through a single pipe, what diameter would be required?

Ans. 16 inches.

Since long horizontal runs of pipe increase the resistance and loss of heat, they should not in general be over 12 or 14 feet in length. This applies especially to pipes leading to rooms on the first floor, or to those on the cold side of the house. Pipes of excessive length should be increased in size because of the added resistance.

Figs. 10 and 11 show common methods of running the pipes in the basement. The first gives the best results, and should be used where the basement is of sufficient height to allow it. A damper should be placed in each pipe near the furnace, for regulating the flow of air to the different rooms, or for shutting it off entirely when desired.

While round pipe risers give the best results, it is not always possible to provide a sufficient space for them, and flat or oval pipes are substituted. When vertical pipes must be placed in single partitions, much better results will be obtained if the studding can be made 5 or 6 inches deep instead of 4 as is usually done. Flues should never in any case be made less than 3½ inches in depth. Each room should be heated by a separate pipe. In some cases, however, it is allowable to run a single riser to heat two unimportant rooms on an upper floor. A clear space of at least ½ inch should be left between the risers and studs, and the latter should be carefully tinned, and the

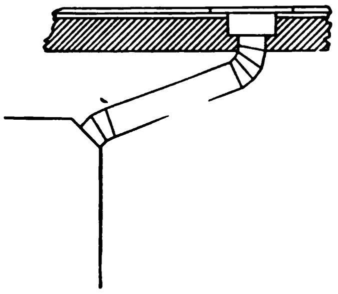


Fig. 10.

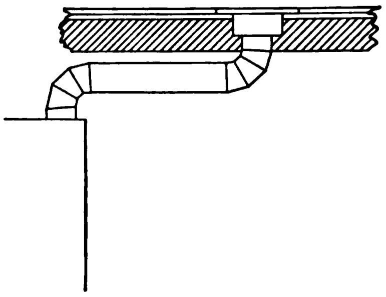


Fig. 11.

Common Methods of Running Hot-Air Pipes in Basement. Method Shown in Fig. 10 is Preferable where Feasible.

TABLE IX

Dimensions of Oval Pipes

Dimension of Pipe	Area in Square Inches
6 ovaled to 5 in.	27
7 " " 4 "	31
7 " " 3½ "	29
7 " " 6 "	38
8 " " 5 "	43
9 " " 4 "	45
9 " " 6 "	57
9 " " 5 "	51
10 " " 3½ "	46
11 " " 4 "	58
12 " " 3½ "	55
10 " " 6 "	67
11 " " 5 "	67
14 " " 4 "	76
15 " " 3½ "	73
12 " " 6 "	85
12 " " 5 "	75
19 " " 4 "	96
20 " " 3½ "	100

space between them on both sides covered with tin, asbestos, or wire lath.

Table IX gives the capacity of oval pipes. A 6-inch pipe ovaled to 5 means that a 6-inch pipe has been flattened out to a thickness of 5 inches, and column 2 gives the resulting area.

Having determined the size of round pipe required, an equivalent oval pipe can be selected from the table to suit the space available.

Registers. The registers which control the supply of warm air to the rooms, generally have a net area equal to two-thirds of their gross area. The net area should be from 10 to 20 per cent greater than the area of the pipe connected with it. It is common practice to use registers having the short dimensions equal to, and the long dimensions about one-half greater than, the diameter of the pipe. This would give standard sizes for different diameters of pipe, as listed in Table X.

TABLE X

Sizes of Registers for Different Sizes of Pipes

DIAMETER OF PIPE	SIZE OF REGISTER
6 in.	6 × 10 in.
7 "	7 × 10 "
8 "	8 × 12 "
9 "	9 × 14 "
10 "	10 × 15 "
11 "	11 × 16 "
12 "	12 × 17 "
13 "	14 × 20 "
14 "	14 × 22 "
15 "	15 × 22 "
16 "	16 × 21 "

Combination Systems. A combination system for heating by hot air and hot water consists of an ordinary furnace with some form of surface for heating water, placed either in contact with the fire or suspended above it. Fig. 12 shows a common arrangement where part of the heating surface forms a portion of the lining to the firepot and the remainder is above the fire.

Care must be taken to proportion properly the work to be done by the air and the water; else one will operate at the expense of the other. One square foot of heating surface in contact with the fire is capable of supplying from 40 to 50 square feet of radiating surface, and one square foot suspended over the fire will supply from 15 to 25 square feet of radiation.

The value or efficiency of the heating surface varies so widely in different makes that it is best to state the required conditions to the manufacturers and have them proportion the surfaces as their experience has found best for their particular type of furnace.

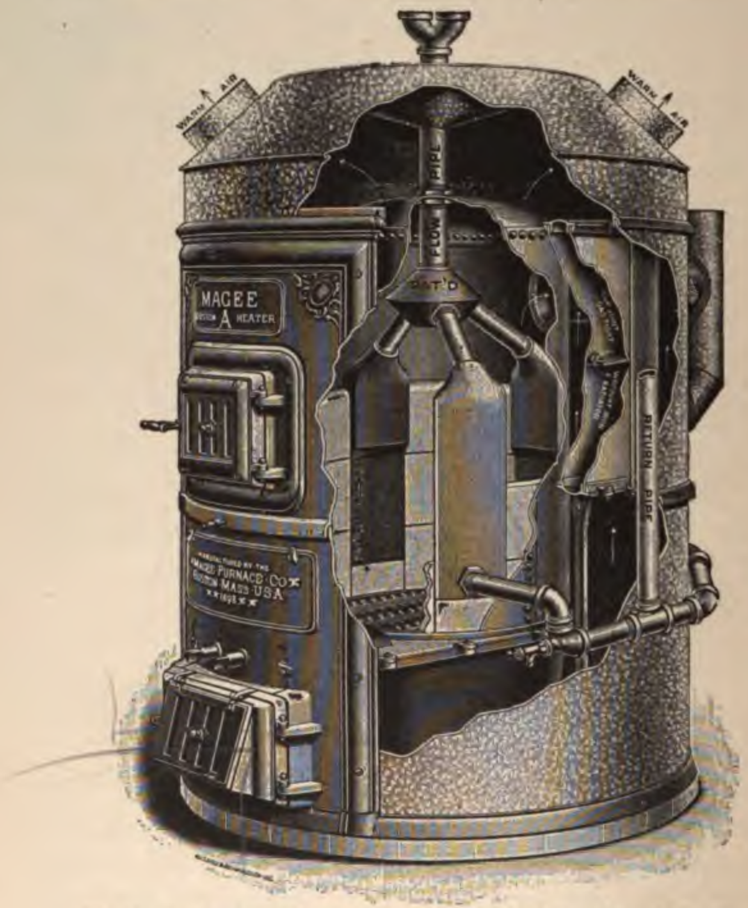


Fig. 12. Combination Furnace, for Heating by Both Hot Air and Hot Water.

Care and Management of Furnaces. The following general rules apply to the management of all hard coal furnaces.

The fire should be thoroughly shaken once or twice daily in cold weather. It is well to keep the firepot heaping full at all times. In this way a more even temperature may be maintained, less attention is required, and no more coal is burned than when the pot is only partly filled. In mild weather the mistake is frequently made of carrying a thin fire, which requires frequent attention and is likely to die out. Instead, to diminish the temperature in the house, keep the firepot full and allow ashes to accumulate on the grate (not under it) by shaking less frequently or less vigorously. The ashes will hold the heat and render it an easy matter to maintain and control the fire. When feeding coal on a low fire, open the drafts and neither rake nor shake the fire till the fresh coal becomes ignited. The air supply to the fire is of the greatest importance. An insufficient amount results in incomplete combustion and a great loss of heat. To secure proper combustion, the fire should be controlled principally by means of the ash-pit through the ash-pit door or slide.

The smoke-pipe damper should be opened only enough to carry off the gas or smoke and to give the necessary draft. The openings in the feed door act as a check on the fire, and should be kept closed during cold weather, except just after firing, when with a good draft they may be partly opened to increase the air-supply and promote the proper combustion of the gases.

Keep the ash-pit clear to avoid warping or melting the grate. The cold-air box should be kept wide open except during winds or when the fire is low. At such times it may be partly, but never completely closed. Too much stress cannot be laid on the importance of a sufficient air-supply to the furnace. It costs little if any more to maintain a comfortable temperature in the house night and day than to allow the rooms to become so cold during the night that the fire must be forced in the morning to warm them up to a comfortable temperature.

In case the warm air fails at times to reach certain rooms, it may be forced into them by temporarily closing the registers in other rooms. The current once established will generally continue after the other registers have been opened.

It is best to burn as hard coal as the draft will warrant. Egg size is better than larger coal, since for a given weight small lumps expose more surface and ignite more quickly than larger ones. The furnace and smoke-pipe should be thoroughly cleaned once a year.

This should be done just after the fire has been allowed to go out in the spring.

STEAM BOILERS

Types. The boilers used for heating are the same as have already been described for power work. In addition there is the cast-iron sectional boiler, used almost exclusively for dwelling-houses.

Tubular Boilers. Tubular boilers are largely used for heating purposes, and are adapted to all classes of buildings except dwelling-houses and the special cases mentioned later, for which sectional boilers are preferable. A *boiler horse-power* has been defined as the evaporation of 34½ pounds of water from and at a temperature of 212 degrees, and in doing this 33,317 B. T. U. are absorbed, which are again given out when the steam is condensed in the radiators. Hence to find the boiler H. P. required for warming any given building, we have only to compute the heat loss per hour by the methods already given, and divide the result by 33,330. It is more common to divide by the number 33,000, which gives a slightly larger boiler and is on the side of safety.

The commercial horse-power of a well-designed boiler is based upon its heating surface; and for the best economy in heating work, it should be so proportioned as to have about 1 square foot heating of surface for each 2 pounds of water to be evaporated from and at 212 degrees F. This gives 34.5 ÷ 2 = 17.2 square feet of heating surface per horse-power, which is generally taken as 15 in practice. Makers of tubular boilers commonly rate them on a basis of 12 square feet of heating surface per horse-power. This is a safe figure under the conditions of power work, where skilled firemen are employed and where more care is taken to keep the heating surfaces free from soot and ashes. For heating plants, however, it is better to rate the boilers upon 15 square feet per horse-power as stated above.

There is some difference of opinion as to the proper method of computing the heating surface of tubular boilers. In general, all surface is taken which is exposed to the hot gases on one side and to the water on the other. A safe rule, and the one by which Table XII is computed, is to take ½ the area of the shell, ⅔ of the rear head, less the tube area, and the interior surface of all the tubes.

The required amount of grate area, and the proper ratio of heating surface to grate area, vary a good deal, depending on the character of the fuel and on the chimney draft. By assuming the probable rates of combustion and evaporation, we may compute the required grate area for any boiler from the formula:

$$S = \frac{H.P. \times 34.5}{E \times C},$$

in which

S = Total grate area, in square feet;

E = Pounds of water evaporated per pound of coal;

C = Pounds of coal burned per square foot of grate per hour.

Table XI gives the approximate grate area per H. P. for different rates of evaporation and combustion as computed by the above equation.

TABLE XI

Grate Area per Horse-Power for Different Rates of Evaporation and Combustion

Pounds of Steam per Pound of Coal	Pounds of Coal Burned per Square Foot of Grate per Hour		
	8 lbs.	10 lbs.	12 lbs.
	Square Feet of Grate Surface per Horse-Power		
10	.43	.35	.28
9	.48	.38	.32
8	.54	.43	.36
7	.62	.49	.41
6	.72	.58	.48

For example, with an evaporation of 8 pounds of steam per pound of coal, and a combustion of 10 pounds of coal per square foot of grate, .43 of a square foot of grate surface per H. P. would be called for.

The ratio of heating to grate surface in this type of boiler ranges from 30 to 40, and therefore allows under ordinary conditions a combustion of from 8 to 10 pounds of coal per square foot of grate. This is easily obtained with a good chimney draft and careful firing. The larger the boiler, the more important the plant usually, and the greater the care bestowed upon it, so that we may generally count on a higher rate of combustion and a greater efficiency as the size of the boiler increases. Table XII will be found very useful in determining the size of boiler required under different conditions. The grate area is computed for an evaporation of 8 pounds of water per pound

TABLE XII

Diameter of Shell in Inches	Number of Tubes	Diameter of Tubes in Inches	Length of Tubes in Feet	Horse-Power	Size of Grate in Inches	Size of Uptake in Inches	Size of Smoke-pipe in Sq. In
30	28	2½	6	8.5	24 x 36	10 x 14	140
			7	9.9	24 x 36	10 x 14	140
			8	11.2	24 x 36	10 x 14	140
			9	12.6	24 x 42	10 x 14	140
			10	14.0	24 x 42	10 x 14	140
36	34	2½	8	13.6	30 x 36	10 x 16	160
			9	15.8	30 x 42	10 x 18	180
			10	16.9	30 x 42	10 x 18	180
			11	18.6	30 x 48	10 x 20	200
			12	20.9	30 x 48	10 x 20	200
42	34	3	9	18.5	36 x 42	10 x 20	200
			10	20.5	36 x 42	10 x 20	200
			11	22.5	36 x 48	10 x 25	250
			12	24.5	36 x 48	10 x 25	250
			13	26.5	36 x 48	10 x 28	280
			14	28.5	36 x 54	10 x 28	280
48	44	3	10	30.4	42 x 48	10 x 28	280
			11	33.2	42 x 48	10 x 28	280
			12	35.7	42 x 54	10 x 32	320
			13	38.3	42 x 54	10 x 32	320
			14	40.8	42 x 60	10 x 36	360
			15	43.4	42 x 60	10 x 36	360
			16	45.9	42 x 60	10 x 36	360
54	54	3	11	34.6	48 x 54	10 x 38	380
			12	37.7	48 x 54	10 x 38	380
			13	40.8	48 x 54	10 x 38	380
			14	43.9	48 x 54	10 x 38	380
			15	47.0	48 x 60	10 x 40	400
			16	50.1	48 x 60	10 x 40	400
	46	3½	17	53.0	48 x 60	10 x 40	400
60	72	3	12	48.4	54 x 60	12 x 40	460
			13	52.4	54 x 60	12 x 40	460
			14	56.4	54 x 60	12 x 40	460
			15	60.4	54 x 66	12 x 42	500
			16	64.4	54 x 66	12 x 42	500
	64	3½	17	71 4	54 x 72	12 x 48	550
			18	75.6	54 x 72	12 x 48	550
66	90	3	14	70.1	60 x 66	12 x 48	500
			15	75.0	60 x 72	12 x 52	620
			16	80.0	60 x 72	12 x 52	620
	78	3½	17	86.0	60 x 78	12 x 56	670
			18	91.1	60 x 78	12 x 56	670
			19	96.2	60 x 78	12 x 56	670
	62	4	20	93.1	60 x 78	12 x 56	670
72	114	3	14	87.4	66 x 72	12 x 56	670
			15	93.6	66 x 72	12 x 56	670
			16	99.7	66 x 78	12 x 62	740
	98	3½	17	106.4	66 x 78	12 x 62	740
			18	112.6	66 x 84	12 x 66	790
			19	118.8	66 x 84	12 x 66	790
	72	4	20	107.8	66 x 84	12 x 66	790

of coal, which corresponds to an efficiency of about 60 per cent, and is about the average obtained in practice for heating boilers.

The areas of uptake and smoke-pipe are figured on a basis of 1 square foot to 7 square feet of grate surface, and the results given in round numbers. In the smaller sizes the relative size of smoke-pipe is greater. The rate of combustion runs from 6 pounds in the smaller sizes to 11½ in the larger. Boilers of the proportions given in the table, correspond well with those used in actual practice, and may be relied upon to give good results under all ordinary conditions.

Water-tube boilers are often used for heating purposes, but more especially in connection with power plants. The method of computing the required H. P. is the same as for tubular boilers.

Sectional Boilers. Fig. 13 shows a common form of cast-iron boiler. It is made up of slabs or sections, each one of which is connected by nipples with headers at the sides and top. The top header acts as a steam drum, and the lower ones act as mud drums; they also receive the water of condensation from the radiators. The gases from the fire pass backward and forward through flues and are finally taken off at the rear of the boiler.

Another common form of sectional boiler is shown in Fig. 14. It is made up of sections which increase the length like the one just described. These boilers have no drum connecting with the sections; but instead, each section connects with the adjacent one through openings at the top and bottom, as shown.

The ratio of heating to grate surface in boilers of this type ranges from 15 to 25 in the best makes. They are provided with the usual attachments, such as pressure-gauge, water-glass, gauge-cocks, and safety-valve; a low-pressure damper regulator is furnished for operating the draft doors, thus keeping the steam pressure practically constant. A pressure of from 1 to 5 pounds is usually carried on these boilers, depending upon the outside temperature. The usual setting is simply a covering of some kind of non-conducting material like plastic magnesia or asbestos, although some forms are enclosed in light brickwork.

In computing the required size, we may proceed in the same manner as in the case of a furnace. For the best types of house-heating boilers, we may assume a combustion of 5 pounds of coal per square foot of grate per hour, and an average efficiency of 60 per cent, which corresponds to 8,000 B. T. U. per pound of coal, available for useful work.

In the case of direct-steam heating, we have only to supply heat to offset that lost by radiation and conduction; so that the grate area may be found by dividing the computed heat loss per hour by 8,000, which gives the number of pounds of coal; and this in turn, divided by 5, will give the area of grate required. The most efficient rate of combustion will depend somewhat upon the ratio between the grate and heating surface. It has been found by experience that about ¼ of a pound of coal per hour for each square foot of heating surface gives the best results; so that, by knowing the ratio of heating surface to grate area for any make of heater, we can easily compute the most efficient rate of combustion, and from it determine the necessary grate area.

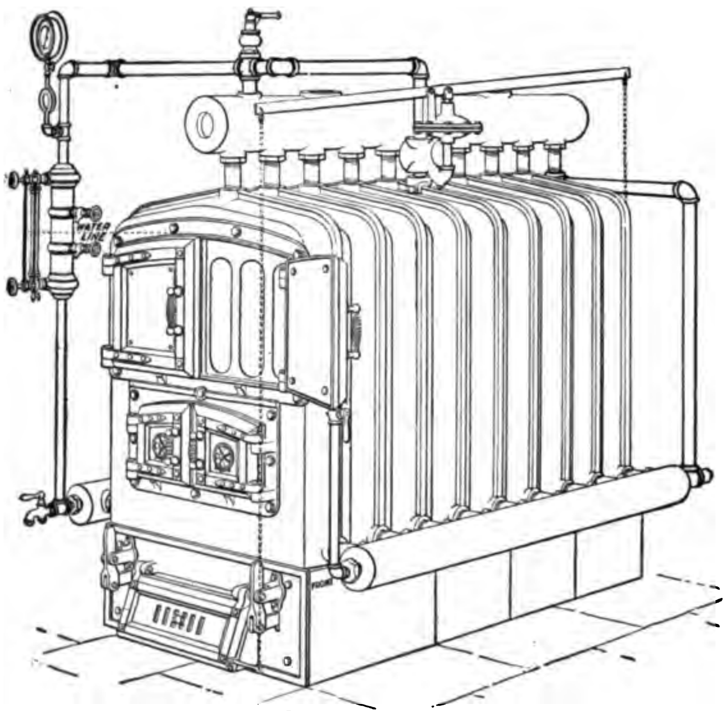


Fig. 13. Common Type of Cast-Iron Sectional Boiler. Note Headers at Sides and Top Acting as Drums.

For example, suppose the heat loss from a building to be 480,000 B. T. U. per hour, and that we wish to use a heater in which the ratio of heating surface to grate area is 24. What will be the most efficient rate of combustion and the required grate area? 480,000 ÷ 8,000 = 60 pounds of coal per hour, and 24 ÷ 4 = 6, which is the best rate of combustion to employ; therefore 60 ÷ 6 = 10, the grate area required.

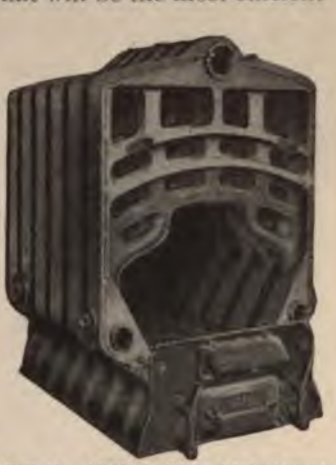


Fig. 14. Another Type of Sectional Boiler. Here there are no drums, the sections being directly connected through openings at top and bottom.
Courtesy of American Radiator Co.

There are many different designs of cast-iron boilers for low-pressure steam and hot-water heating. In general, boilers having a drum connected by nipples with each section give dryer steam and hold a steadier water-line than the second form, especially when forced above their normal capacity. The steam, in passing through the openings between successive sections in order to reach the outlet, is apt to carry with it more or less water, and to choke the openings, thus producing an uneven pressure in different parts of the boiler.

In the case of hot-water boilers this objection disappears.

In order to adapt this type of boiler to steam work, the opening between the sections should be of good size, with an ample steam space above the water-line; and the nozzles for the discharge of steam should be located at frequent intervals.

EXAMPLES FOR PRACTICE

1. The heat loss from a building is 240,000 B. T. U. per hour, and the ratio of heating to grate area in the heater to be used is 20. What will be the required grate area? Ans. 6 sq. ft.

2. The heat loss from a building is 168,000 B. T. U. per hour, and the chimney draft is such that not over 3 pounds of coal per hour can be burned per square foot of grate. What ratio of heating to grate area will be necessary, and what will be the required grate area? Ans. Ratio, 12. Grate area, 7 sq. ft.

Cast-iron sectional boilers are used for dwelling-houses, small schoolhouses, churches, etc., where low pressures are carried. They are increased in size by adding more slabs or sections. After a certain length is reached, the rear sections become less and less efficient, thus limiting the size and power.

Horse-Power for Ventilation. We already know that one B. T. U. will raise the temperature of 1 cubic foot of air 55 degrees, or it will raise 100 cubic feet $\frac{1}{100}$ of 55 degrees, or $\frac{55}{100}$ of 1 degree; therefore, to raise 100 cubic feet 1 degree, it will take $1 \div \frac{55}{100}$, or $\frac{100}{55}$ B. T. U.; and to raise 100 cubic feet through 100 degrees, it will take $\frac{100}{55} \times 100$ B. T. U. In other words, the B. T. U. required to raise any given volume of air through any number of degrees in temperature, is equal to

$$\frac{\text{Volume of air in cubic ft.} \times \text{Degrees raised}}{55}$$

Example. How many B. T. U. are required to raise 100,000 cubic feet of air 70 degrees?

$$\frac{100{,}000 \times 70}{55} = 127{,}272 +$$

To compute the H. P. required for the ventilation of a building, we multiply the total air-supply, in cubic feet per hour, by the number of degrees through which it is to be raised, and divide the result by 55. This gives the B. T. U. per hour, which, divided by 33,000, will give the H. P. required. In using this rule, always take the air-supply in cubic feet per *hour*.

EXAMPLES FOR PRACTICE

1. The heat loss from a building is 1,650,000 B. T. U. per hour. There is to be an air-supply of 1,500,000 cubic feet per hour, raised through 70 degrees. What is the total boiler H. P. required?

Ans. 108.

2. A high school has 10 classrooms, each occupied by 50 pupils. Air is to be delivered to the rooms at a temperature of 70 degrees. What will be the total H. P. required to heat and ventilate the building when it is 10 degrees below zero, if the heat loss through walls and windows is 1,320,000 B. T. U. per hour? Ans. 106+.

DIRECT-STEAM HEATING

A system of direct-steam heating consists (1) of a furnace and boiler for the combustion of fuel and the generation of steam; (2) a system of pipes for conveying the steam to the radiators and for returning the water of condensation to the boiler; and (3) radiators or coils placed in the rooms for diffusing the heat.

Various types of boilers are used, depending upon the size and kind of building to be warmed. Some form of cast-iron sectional boiler is commonly used for dwelling-houses, while the tubular or water-tube boiler is more usually employed in larger buildings. Where the boiler is used for heating purposes only, a low steam-pressure of from 2 to 10 pounds is carried, and the condensation flows back by gravity to the boiler, which is placed below the lowest radiator. When, for any reason, a higher pressure is required, the steam for the heating system is made to pass through a reducing valve, and the condensation is returned to the boiler by means of a pump or return trap.

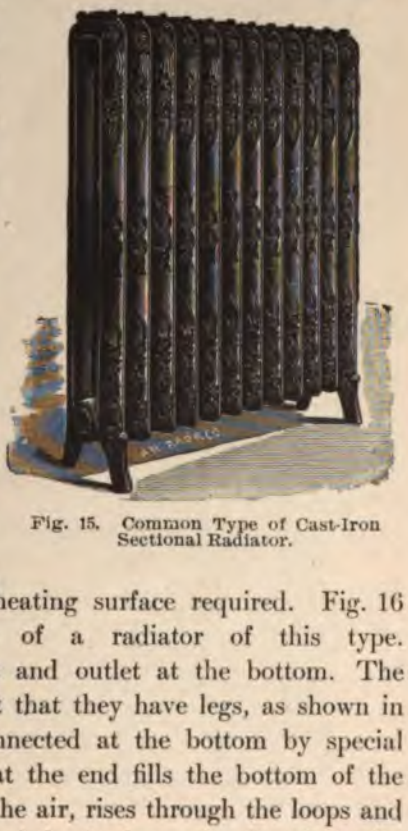


Fig. 15. Common Type of Cast-Iron Sectional Radiator.

Types of Radiating Surface. The radiation used in direct-steam heating is made up of cast-iron radiators of various forms, pipe radiators, and circulation coils.

Cast-Iron Radiators. The general form of a cast-iron sectional radiator is shown in Fig. 15. Radiators of this type are made up of sections, the number depending upon the amount of heating surface required. Fig. 16 shows an intermediate section of a radiator of this type. It is simply a loop with inlet and outlet at the bottom. The end sections are the same, except that they have legs, as shown in Fig. 17. These sections are connected at the bottom by special nipples, so that steam entering at the end fills the bottom of the radiator, and, being lighter than the air, rises through the loops and forces the air downward and toward the farther end, where it is discharged through an air-valve placed about midway of the last section. There are many different designs varying in height and width, to suit all conditions. The wall pattern shown in Fig. 18 is very convenient when it is desired to place the radiator above the floor, as in bathrooms, etc.; it is also a convenient form to place under the windows of halls and churches to counteract the effect of cold down drafts. It is adapted to nearly every place where the ordinary direct radiator can be used, and may be connected up in different ways to meet the various requirements.

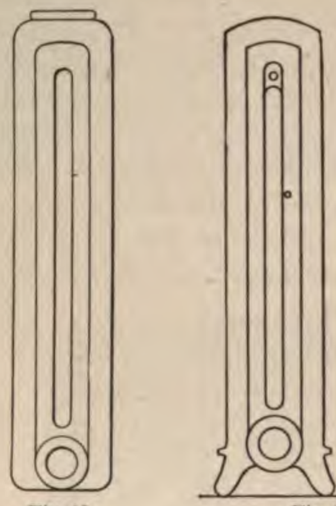


Fig. 16. Fig. 17.

Intermediate and End Sections of Radiator Shown in Fig. 15. The end sections (at right) have legs.

A low and moderately shallow radiator, with ample space for the circulation of air between the sections, is more efficient than a deep radiator with the sections closely packed together. One- and two-column radiators, so called, are preferable to three- and four-column, when there is sufficient space to use them.

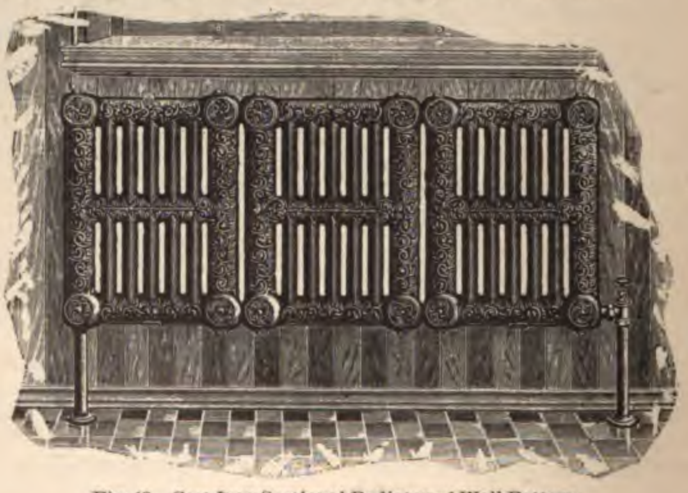


Fig. 18. Cast-Iron Sectional Radiator of Wall Pattern.

The standard height of a radiator is 36 or 38 inches, and, if possible, it is better not to exceed this.

For small radiators, it is better practice to use lower sections and increase the length; this makes the radiator slightly more efficient and gives a much better appearance.

To get the best results from wall radiators, they should be set out at least 1½ inches from the wall to allow a free circulation of air back of them. Patterns having cross-bars should be placed, if possible, with the bars in a vertical position, as their efficiency is impaired somewhat when placed horizontally.

Pipe Radiators. This type of radiator (see Fig. 19) is made up of wrought-iron pipes screwed into a cast-iron base. The pipes are either connected in pairs at the top by return bends, or each separate tube has a thin metal diaphragm passing up the center nearly to the top. It is necessary that a loop be formed, else a "dead end" would occur. This would become filled with air and prevent steam from entering, thus causing portions of the radiator to remain cold.

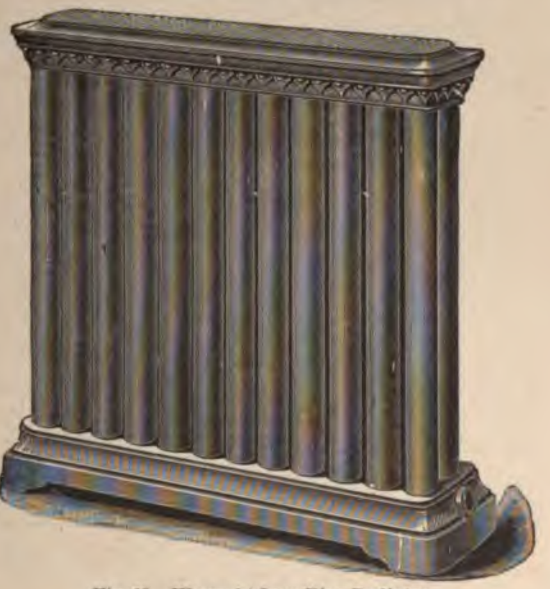


Fig. 19. Wrought-Iron Pipe Radiator.

Circulation Coils. These are usually made up of 1 or 1¼-inch wrought-iron pipe, and may be hung on the walls of a room by means of hook plates, or suspended overhead on hangers and rolls.

Fig. 20 shows a common form for schoolhouse and similar work; this coil is usually made of 1¼-inch pipe screwed into *headers* or *branch tees* at the ends, and is hung on the wall just below the windows. This is known as a *branch coil.* Fig. 21 shows a *trombone coil,* which is commonly used when the pipes cannot turn a corner, and where the entire coil must be placed upon one side of the room. Fig. 22

is called a *miter coil,* and is used under the same conditions as a trombone coil if there is room for the vertical portion. This form is not so pleasing in appearance as either of the other two, and is found only in factories or shops, where looks are of minor importance.

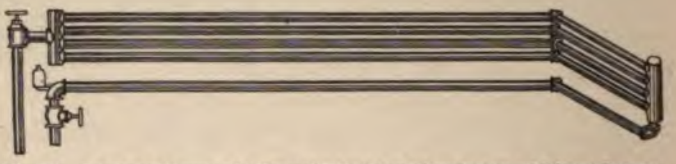


Fig. 20. Common Form of "Branch" Coil for Circulation of Direct Steam.

Overhead coils are usually of the miter form, laid on the side and suspended about a foot from the ceiling; they are less efficient than when placed nearer the floor, as the warm air stays at the ceiling and the lower part of the room is likely to remain cold. They are used only when wall coils or radiators would be in the way of fixtures, or when they would come below the water-line of the boiler if placed near the floor.

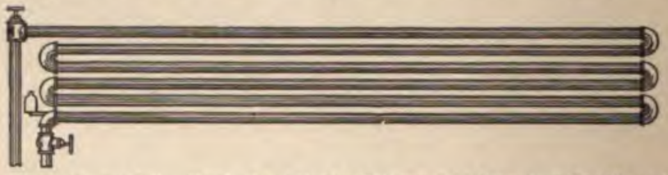


Fig. 21. "Trombone" Coil. Used where Entire Coil must be Placed on One Side of Room

When steam is first turned on a coil, it usually passes through a portion of the pipes first and heats them while the others remain cold and full of air. Therefore the coil must always be made up in such a way that each pipe shall have a certain amount of spring and may expand independently without bringing undue strains upon the others. Circulation coils should incline about 1 inch in 20 feet toward the

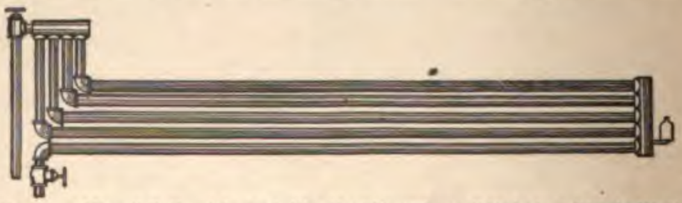


Fig. 22. "Miter" Coil. Adapted, like the "Trombone," Only to a Single Wall. Frequently Used in Factories and Shops.

return end in order to secure proper drainage and quietness of operation.

Efficiency of Radiators. The efficiency of a radiator—that is, the B. T. U. which it gives off per square foot of surface per hour—depends upon the difference in temperature between the steam in the radiator and the surrounding air, the velocity of the air over the radiator, and the quality of the surface, whether smooth or rough. In ordinary low-pressure heating, the first condition is practically constant; but the second varies somewhat with the pattern of the radiator. An open design which allows the air to circulate freely over the radiating surfaces, is more efficient than a closed pattern, and for this reason a pipe coil is more efficient than a radiator.

In a large number of tests of cast-iron and pipe radiators, working under usual conditions, the heat given off per square foot of surface per hour for each degree difference in temperature between the steam and surrounding air was found to average about 1.7 B. T. U. The temperature of steam at 3 pounds' pressure is 220 degrees, and 220—70 =150, which may be taken as the average difference between the temperature of the steam and the air of the room, in ordinary low-pressure work. Taking the above results, we have 150 × 1.7 = 255 B. T. U. as the efficiency of an average cast-iron or pipe radiator. This, for convenient use, may be taken as 250. A circulation coil made up of pipes from 1 to 2 inches in diameter, will easily give off 300 B. T. U. under the same conditions; and a cast-iron wall radiator with ample space back of it should have an efficiency equal to that of a wall coil. While overhead coils have a higher efficiency than cast-iron radiators, their position near the ceiling reduces their effectiveness, so that in practice the efficiency should not be taken over 250 B. T. U. per hour at the most. Tabulating the above we have:

TABLE XIII

Efficiency of Radiators, Coils, etc.

Type of Radiating Surface	Radiation per Square Foot of Surface per Hour	
Cast-Iron Sectional and Pipe Radiators	250	B. T. U.
Wall Radiators	300	"
Ceiling Coils	200 to 250	"
Wall Coils	300	"

If the radiator is for warming a room which is to be kept at a temperature above or below 70 degrees, or if the steam pressure is greater than 3 pounds, the radiating surface may be changed in the same proportion as the difference in temperature between the steam and the air.

For example, if a room is to be kept at a temperature of 60°, the efficiency of the radiator becomes $\frac{150}{140} \times 250 = 268$; that is, the efficiency varies directly as the difference in temperature between the steam and the air of the room. It is not customary to consider this unless the steam pressure should be raised to 10 or 15 pounds or the temperature of the rooms changed 15 or 20 degrees from the normal.

From the above it is easy to compute the size of radiator for any given room. First compute the heat loss per hour by conduction and leakage in the coldest weather; then divide the result by the efficiency of the type of radiator to be used. It is customary to make the radiators of such size that they will warm the rooms to 70 degrees in the coldest weather. As the low-temperature limit varies a good deal in different localities, even in the same State, the lowest temperature for which we wish to provide must be settled upon before any calculations are made. In New England and through the Middle and Western States, it is usual to figure on warming a building to 70 degrees when the outside temperature is from zero to 10 degrees below.

The different makers of radiators publish in their catalogues, tables giving the square feet of heating surface for different styles and heights, and these can be used in determining the number of sections required for all special cases.

If pipe coils are to be used, it becomes necessary to reduce square feet of heating surface to linear feet of pipe; this can be done by means of the factors given below.

$$\text{Square feet of heating surface} \times \begin{cases} 3 & = \text{linear ft. of 1 -in. pipe} \\ 2.3 & = \text{`` \quad `` \quad } 1\tfrac{1}{4}\text{-in. \quad ``} \\ 2 & = \text{`` \quad `` \quad } 1\tfrac{1}{2}\text{-in. \quad ``} \\ 1.6 & = \text{`` \quad `` \quad 2 -in. \quad ``} \end{cases}$$

The size of radiator is made only sufficient to keep the room warm after it is once heated; and no allowance is made for *warming up*; that is, the heat given off by the radiator is just equal to that lost through walls and windows. This condition is offset in two ways—

first, when the room is cold, the difference in temperature between the steam and the air of the room is greater, and the radiator is more efficient; and *second*, the radiator is proportioned for the coldest weather, so that for a greater part of the time it is larger than necessary.

EXAMPLES FOR PRACTICE

1. The heat loss from a room is 25,000 B. T. U. per hour in the coldest weather. What size of direct radiator will be required?
Ans. 100 square feet.

2. A schoolroom is to be warmed with circulation coils of $1\frac{1}{4}$-inch pipe. The heat loss is 30,000 B. T. U. per hour. What length of pipe will be required? Ans. 230 linear feet.

Location of Radiators. Radiators should, if possible, be placed in the coldest part of the room, as under windows or near outside doors. In living rooms it is often desirable to keep the windows free, in which case the radiators may be placed at one side. Circulation coils are run along the outside walls of a room under the windows. Sometimes the position of the radiators is decided by the necessary location of the pipe risers, so that a certain amount of judgment must be used in each special case as to the best arrangement to suit all requirements.

Systems of Piping. There are three distinct systems of piping, known as the *two-pipe system*, the *one-pipe relief system*, and the *one-pipe circuit system*, with various modifications of each and combinations of the different systems.

Fig. 23 shows the arrangement of piping and radiators in the two-pipe system. The steam main leads from the top of the boiler, and the branches are carried along near the basement ceiling. Risers are taken from the supply branches, and carried up to the radiators on the different floors; and return pipes are brought down to the return mains, which should be placed near the basement floor below the water-line of the boiler. Where the building is more than two stories high, radiators in similar positions on different floors are connected with the same riser, which may run to the highest floor; and a corresponding return drop connecting with each radiator is carried down beside the riser to the basement. A system in which the main horizontal returns are below the water-line of the boiler is said to have a *wet* or *sealed* return. If the returns are overhead and above the water-line, it is called a *dry* return. Where the steam is exposed to extended surfaces of water, as in overhead returns, where the condensation partially fills the pipes, there is likely to be cracking or *water-hammer*, due to the sudden condensation of the steam as it comes in contact with the cooler water. This is especially noticeable when steam is first turned into cold pipes and radiators, and the condensation is excessive. When dry returns are used, the pipes should be large and have a good pitch toward the boiler.

In the case of sealed returns, the only contact between the steam and standing water is in the vertical returns, where the exposed surfaces are very small (being equal to the sectional area of the pipes), and trouble from water-hammer is practically done away with. Dry returns should be given an incline of at least 1 inch in 10 feet, while for wet returns 1 inch in 20 or even 40 feet is ample. The ends of all steam mains and branches should be dripped into the returns. If the return is sealed, the drip may be directly connected as shown in Fig. 24; but if it is dry, the connection should be provided with a siphon loop as indicated in Fig. 25. The loop becomes filled with water, and prevents steam from flowing directly into the return. As the

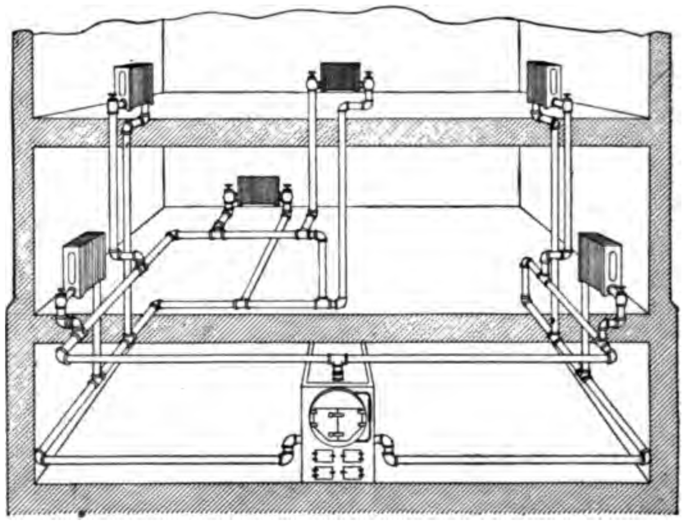


Fig. 23. Arrangement of Piping and Radiators in "Two-Pipe" System.

condensation collects in the loop, it overflows into the return pipe and is carried away. The return pipes in this case are of course filled with steam above the water; but it is steam which has passed through the radiators and their return connections, and is therefore at a slightly lower pressure; so that, if steam were admitted directly from the main, it would tend to hold back the water in more distant returns and cause surging and cracking in the pipes. Sometimes the boiler is at a lower level than the basement in which the returns are run, and it then becomes necessary to establish a *false* water-line. This is done by making connections as shown in Fig. 26.

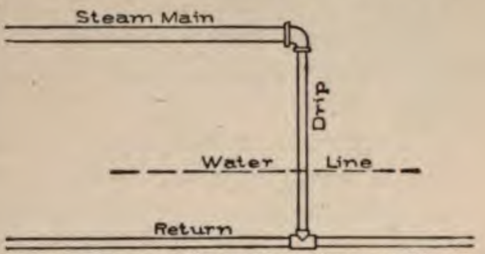


Fig. 24. Drip from Steam Main Connected Directly to Sealed Return.

It is readily seen that the return water, in order to reach the boiler, must flow through the trap, which raises the water-line or seal to the level shown by the dotted line. The balance pipe is to equalize the pressure above and below the water in the trap, and prevent siphonic action, which would tend to drain the water out of the return mains after a flow was once started.

The balance pipe, when possible, should be 15 or 20 feet in length, with a throttle-valve placed near its connection with the main. This valve should be opened just enough to allow the steam-pressure to act upon the air which occupies the space above the water in the trap; but it should not be opened sufficiently to allow the steam to enter in large volume and drive the air out. The success of this arrangement depends upon keeping a layer or cushion of cool air next to the surface of the water in the trap, and this is easily done by following the method here described.

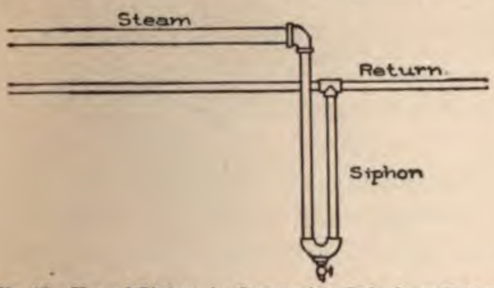


Fig. 25. Use of Siphon in Connecting Drip from Steam Main to a "Dry" Return.

One-Pipe Relief System. In this system of piping, the radiators have but a single connection, the steam flowing in and the condensation draining out through the same pipe. Fig. 27 shows the method of running the pipes for this system. The steam main, as before, leads from the top of the boiler, and is carried to as high a point as the basement ceiling will allow; it then slopes downward with a grade of about 1 inch in 10 feet, and makes a circuit of the building or a portion of it.

Risers are taken from the top and carried to the radiators above, as in the two-pipe system; but in this case, the condensation flows back through the same pipe, and drains into the return main near the floor through drip connections which are made at frequent intervals. In a two-story building, the bottom of each riser to the second floor is dripped; and in larger buildings, it is customary to drip each riser that has more than one radiator connected with it. If the radiators are large and at a considerable distance from the next riser, it is better to make a drip connection for each radiator. When the return main is overhead, the risers should be dripped through siphon loops; but the ends of the branches should make direct connection with the returns. This is the reverse of the two-pipe system. In this case the lowest pressure is at the ends of the mains, so that steam introduced into the returns at these points will cause no trouble in the pipes connecting between these and the boiler.

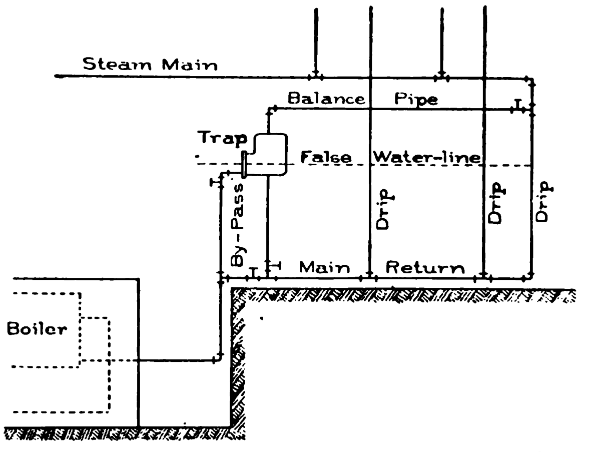


Fig. 26. Connections Made to Establish "False" Water-Line when Boiler is below Basement Level.

If no steam is allowed to enter the returns, a vacuum will be formed, and there will be no pressure to force the water back to the boiler. A check-valve should always be placed in the main return near the boiler, to prevent the water from flowing out in case of a vacuum being formed suddenly in the pipes.

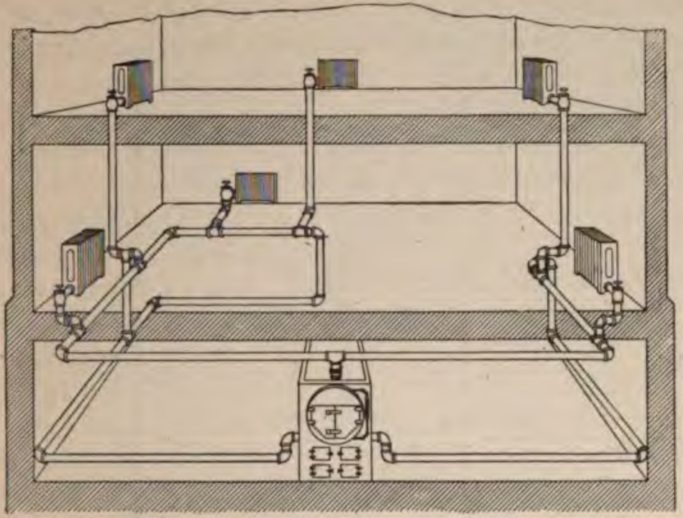


Fig. 27. Arrangement of Piping and Radiators in "One-Pipe Relief" System.

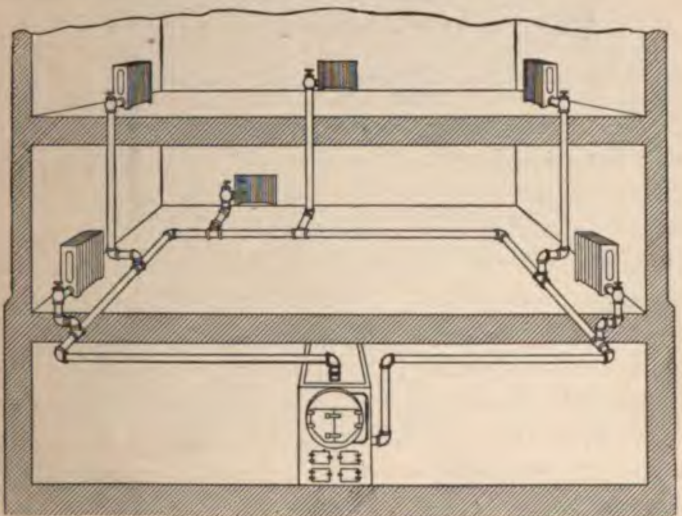


Fig. 28. Arrangement of Piping and Radiators in "One-Pipe Circuit" System.

There is but little difference in the cost of the two systems, as larger pipes and valves are required for the single-pipe method.

With radiators of medium size and properly proportioned connections, the single-pipe system in preferable, there being but one valve to operate and only one-half the number of risers passing through the lower rooms.

One-Pipe Circuit System. In this case, illustrated in Fig. 28, the steam main rises to the highest point of the basement, as before; and then, with a considerable pitch, makes an entire circuit of the building, and again connects with the boiler below the water-line. Single risers are taken from the top; and the condensation drains back through the same pipes, and is carried along with the flow of steam to the extreme end of the main, where it is returned to the boiler. The main is made large, and of the same size throughout its entire length. It must be given a good pitch to insure satisfactory results.

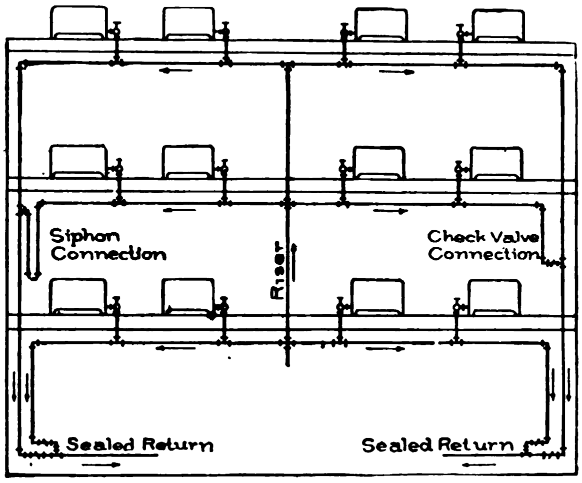
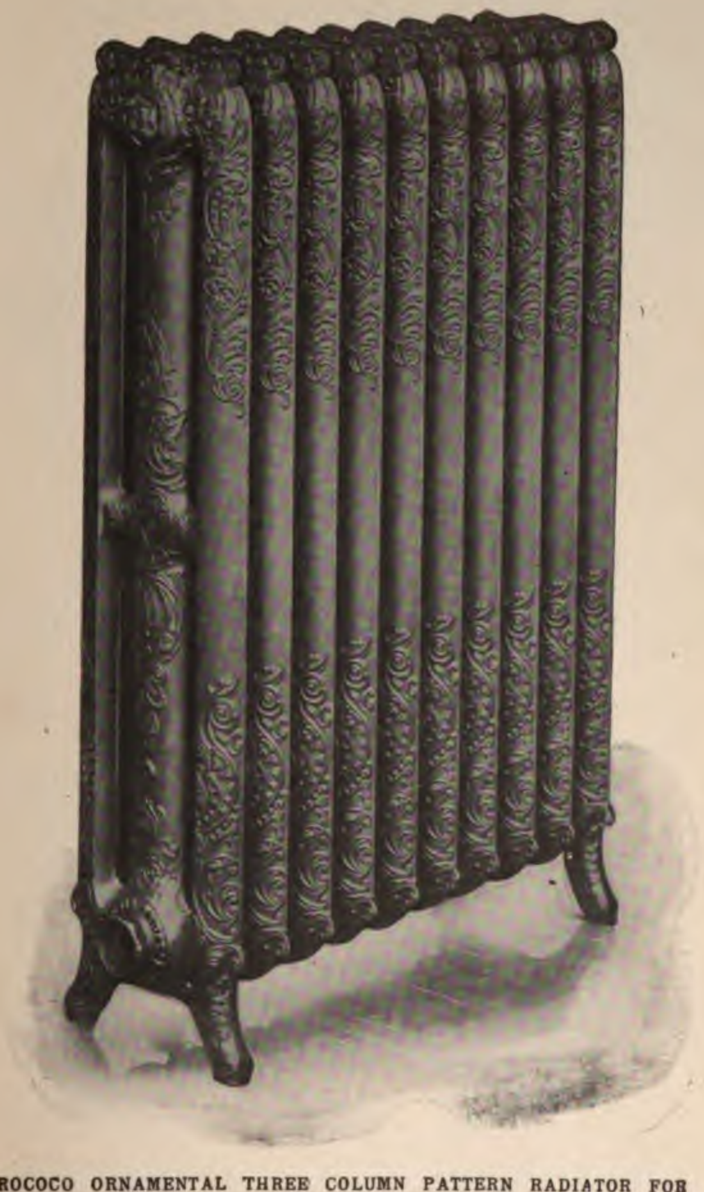


Fig. 29. "One-Pipe Circuit" System. Adapted to a Large Building.

One objection to a single-pipe system is that the steam and return water are flowing in opposite directions, and the risers must be made of extra large size to prevent any interference. This is overcome in large buildings by carrying a single riser to the attic, large enough to supply the entire building; then branching and running "drops" to the basement. In this system the flow of steam is downward, as well as that of water. This method of piping may be used with good results in two-pipe systems as well. Care must always be taken that no pockets or low points occur in any of the lines of pipe; but if for any reason they cannot be avoided, they should be carefully drained.

A modification of this system, adapting it to large buildings, is shown in diagram in Fig. 29. The riser shown in this case is one of



ROCOCO ORNAMENTAL THREE COLUMN PATTERN RADIATOR FOR WARMING BY HOT WATER.
American Radiator Company.

several, the number depending upon the size of the building; and may be supplied at either bottom or top as most desirable. If steam is supplied at the bottom of the riser, as shown in the cut, all of the drip connections with the return drop, except the upper one, should be sealed with either a siphon loop or a check-valve, to prevent the steam from short-circuiting and holding back the condensation in the returns above. If an overhead supply is used, the arrangement should be the reverse; that is, all return connections should be sealed except the lowest.

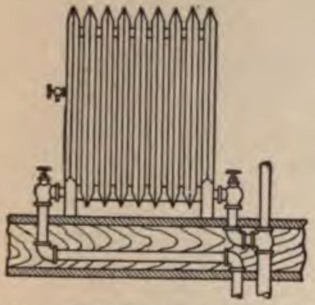


Fig. 30. "Two-Pipe" Connection of Radiator to Riser and Return.

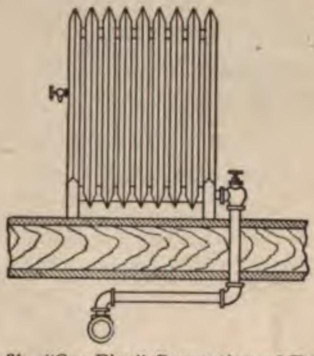


Fig. 31. "One-Pipe" Connection of Radiator to Basement Main.

Sometimes a separate drip is carried down from each set of radiators, as shown on the lower story, being connected with the main return below the water-line of the boiler. In case this is done, it is well to provide a check-valve in each drip below the water-line.

In buildings of any considerable size, it is well to divide the piping system into sections by means of valves placed in the corresponding supply and return branches. These are for use in case of a break in any part of the system, so that it will be necessary to shut off only a small part of the heating system during repairs. In tall buildings, it is customary to place valves at the top and bottom of each riser, for the same purpose.

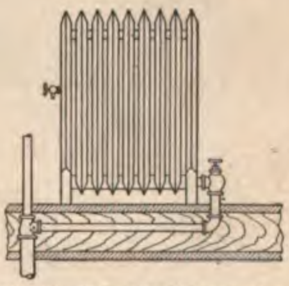


Fig. 32. "One-Pipe" Connection of Radiator to Riser.

Radiator Connections. Figs. 30, 31, and 32 show the common methods of making connections between supply pipes and radiators. Fig. 30 shows a two-pipe connection with a riser; the return is carried down to the main below. Fig. 31 shows a single-pipe connection with a basement main; and Fig. 32, a single connection with a riser.

Care must always be taken to make the horizontal part of the piping between the radiator and riser as short as possible, and to give it a good pitch toward the riser. There are various ways of making these connections, especially suited to different conditions; but the examples given serve to show the general principle to be followed.

Figs. 20, 21, and 22 show the common methods of making steam and return connections with circulation coils. The position of the air-valve is shown in each case.

Expansion of Pipes. Cold steam pipes expand approximately 1 inch in each 100 feet in length when low-pressure steam is turned into them; so that, in laying out a system of piping, we must arrange it in such a manner that there will be sufficient "spring" or "give" to the pipes to prevent injurious strains. This is done by means of offsets and bends. In the case of larger pipes this simple method will not be sufficient, and swivel or slip joints must be used to take up the expansion.

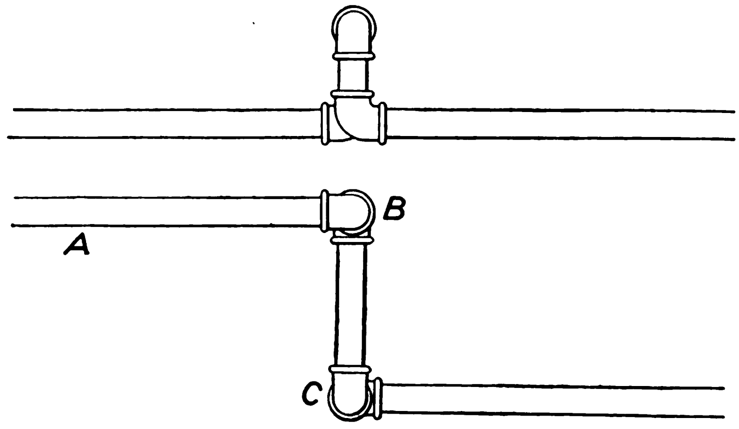


Fig. 33. Elevation and Plan of Swivel-Joint to Counteract Effects of Expansion and Contraction in Pipes.

The method of making up a swivel-joint is shown in Fig. 33. Any lengthening of the pipe *A* will be taken up by slight turning or swivel movements at the points *B* and *C*. A slip-joint is shown in

Fig. 34. The part *c* slides inside the shell *d*, and is made steam-tight by a stuffing-box, as shown. The pipes are connected at the flanges *A* and *B*.

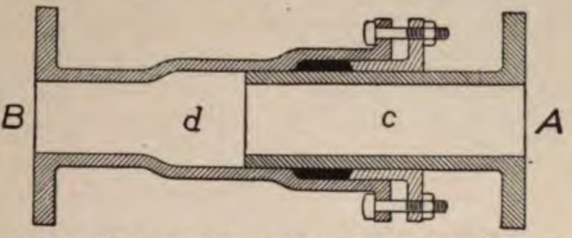


Fig. 34. "Slip-Joint" Connection to Take Care of Expansion and Contraction of Pipes.

When pipes pass through floors or partitions, the woodwork should be protected by galvanized-iron sleeves having a diameter from ¾ to 1 inch greater than the pipe. Fig. 35 shows a form of adjustable floor-sleeve which may be lengthened or shortened to conform to the thickness of floor or partition. If plain sleeves are used, a plate should be placed around the pipe where it passes through the floor or partition. These are made in two parts so that they may be put in place after the pipe is hung. A plate of this kind is shown in Fig. 36.

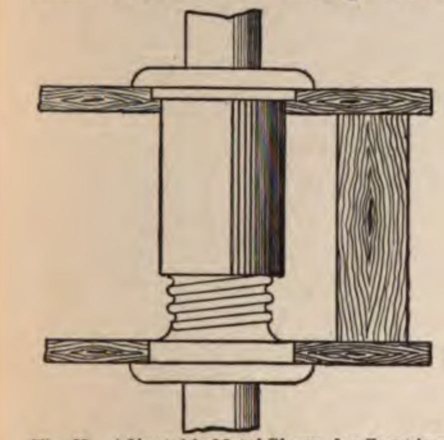


Fig. 35. Adjustable Metal Sleeve for Carrying Pipe through Floor or Partition.

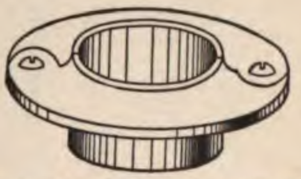


Fig. 36. Floor-Plate Adjusted to Plain Sleeve for Carrying Pipe through Floor or Partition.

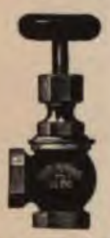


Fig. 37. Angle Valve.

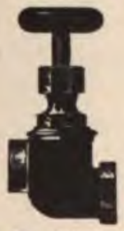


Fig. 38. Offset Valve.

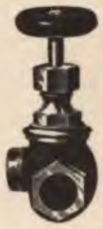


Fig. 39. Corner Valve.

Valves for Radiator Connections.

Valves. The different styles commonly used for radiator connections are shown in Figs. 37, 38, and 39, and are known as *angle, offset,* and *corner* valves, respectively. The first is used when the radiator is at the top of a riser or when the connections are like those shown in Figs. 30, 31, and 32; the second is used when the connection between the riser and radiator is above the floor; and the third, when the radiator has to be set close in the corner of a room and there is not space for the usual connection.

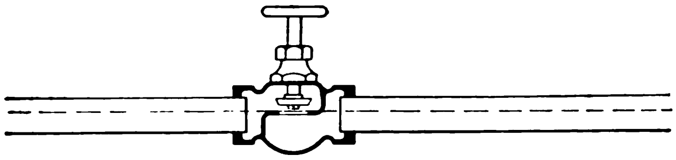


Fig. 40. Indicating Effect of Using Globe Valve on Horizontal Steam Supply Pipe or Dry Return.

A *globe* valve should never be used in a horizontal steam supply or dry return. The reason for this is plainly shown in Fig. 40. In order for water to flow through the valve, it must rise to a height shown by the dotted line, which would half fill the pipes, and cause serious trouble from water-hammer. The gate valve shown in Fig. 41 does not have this undesirable feature, as the opening is on a level with the bottom of the pipe.

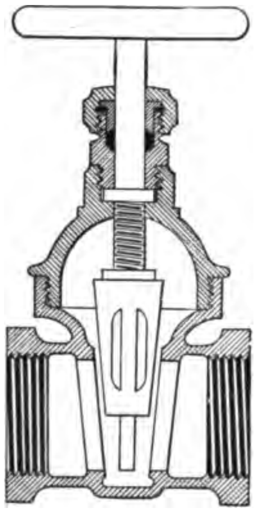


Fig. 41. Gate Valve.

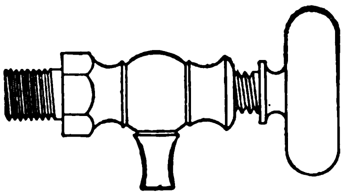


Fig. 42. Simplest Form of Air-Valve. Operated by Hand.

Air-Valves. Valves of various kinds are used for freeing the radiators from air when steam is turned on. Fig. 42 shows the simplest form, which is operated by hand. Fig. 43 is a type of automatic valve, consisting of a shell, which is attached to the radiator. *B* is a small opening which may be closed by the spindle *C*, which is provided with a conical end. *D* is a strip composed of a layer of iron or steel and one of brass soldered or brazed together. The action of the valve is as follows: when the radiator is cold and filled with air the valve stands as shown in the cut. When steam is turned on, the air is driven out through the opening *B*. As soon as this is expelled and steam strikes the strip *D*, the two prongs spring apart owing to the unequal expansion of the two metals due to the heat of the steam. This raises the spindle *C*, and closes the opening so that no steam can escape. If air should collect in the valve, and the metal strip become cool, it would contract, and the spindle would drop and allow the air to escape through *B* as before. *E* is an adjusting nut. *F* is a float attached to the spindle, and is supposed, in case of a sudden rush of water with the air, to rise and close the opening; this action, however, is somewhat uncertain, especially if the pressure of water continues for some time.

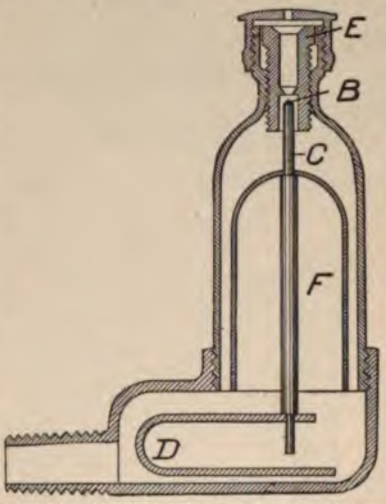


Fig. 43. Radiator Automatic Air-Valve. Operated by Metal Strip *D*, Consisting of Two Pieces of Metal of Unequal Expansive Power.

There are other types of valves acting on the same principle. The valve shown in Fig. 44 is closed by the expansion of a piece of vulcanite instead of a metal strip, and has no water float.

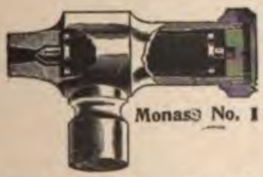


Fig. 44. Automatic Air-Valve. Closed by Expansion of a Piece of Vulcanite.

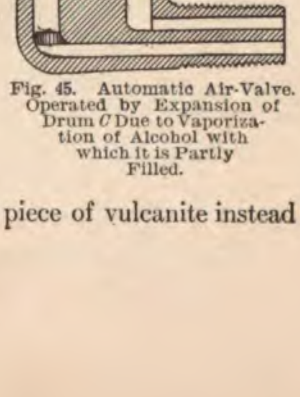


Fig. 45. Automatic Air-Valve. Operated by Expansion of Drum *C* Due to Vaporization of Alcohol with which it is Partly Filled.

The valve shown in Fig. 45 acts on a somewhat different principle. The float *C* is made of thin brass, closed at top and bottom, and is partially filled with wood alcohol. When steam strikes the float, the alcohol is vaporized, and creates a pressure sufficient to bulge out the ends slightly, which raises the spindle and closes the opening *B*.

Fig. 46 shows a form of so-called *vacuum valve.* It acts in a similar manner to those already described, but has in addition a ball check which prevents the air from being drawn into the radiator, should the steam go down and a vacuum be formed. If a partial vacuum exists in the boiler and radiators, the boiling point, and consequently the temperature of the steam, are lowered, and less heat is given off by the radiators. This method of operating a heating plant is sometimes advocated for spring and fall, when little heat is required, and when steam under pressure would overheat the rooms.

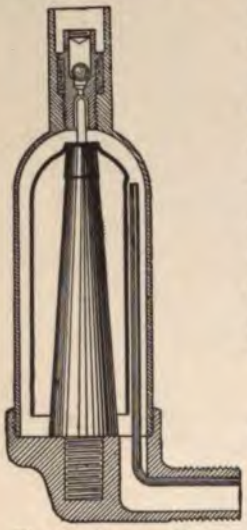


Fig. 46. Vacuum Valve.

Pipe Sizes. The proportioning of the steam pipes in a heating plant is of the greatest importance, and should be carefully worked out by methods which experience has proved to be correct. There are several ways of doing this; but for ordinary conditions, Tables XIV, XV, and XVI have given excellent results in actual practice. They have been computed from what is known as D'Arcy's formula, with suitable corrections made for actual working conditions. As the computations are somewhat complicated, only the results will be given here, with full directions for their proper use.

Table XIV gives the flow of steam in pounds per minute for pipes of different diameters and with varying drops in pressure between the supply and discharge ends of the pipe. These quantities are for pipes 100 feet in length; for other lengths the results must be corrected by the factors given in Table XVI. As the length of pipe increases, friction becomes greater, and the quantity of steam discharged in a given time is diminished.

Table XIV is computed on the assumption that the drop in

TABLE XIV

Flow of Steam in Pipes of Various Sizes, with Various Drops in Pressure between Supply and Discharge Ends

Calculated for 100-Foot Lengths of Pipe

DIAM. OF PIPE	DROP IN PRESSURE (POUNDS)								
	¼	½	¾	1	1½	2	3	4	5
1	.44	.63	.78	91	1.13	1.31	1.66	1.97	2.26
1¼	.81	1.16	1.43	1.66	2.05	2.39	3.02	3.59	4.12
1½	1.06	1.89	2.34	2.71	3.36	3.92	4.94	5.88	6.75
2	2.93	4.17	5.16	5.99	7.43	8.65	10.9	13.0	14.9
2½	5.29	7.52	9.32	10.8	13.4	15.6	19.7	23.4	26.9
3	8.61	12.3	15.2	17.6	21.8	25.4	32	31.8	43.7
3½	12.9	18.3	22.6	26.3	32.5	37.9	47.8	56.9	65.3
4	18 1	25.7	31.8	36.9	45.8	53.3	67.2	80.1	91.9
5	32.2	45.7	56.6	65.7	81.3	94.7	120	142	163
6	51.7	73.3	90.9	106	131	152	192	229	262
7	76.7	109	135	157	194	226	285	339	390
8	108	154	190	222	274	319	402	478	549
9	147	209	258	299	371	432	545	649	745
10	192	273	339	393	487	567	715	852	977
12	305	434	537	623	771	899	1,130	1,350	1,550
15	535	761	942	1,090	1,350	1,580	1,990	2,370	2,720

pressure between the two ends of the pipe equals the initial pressure. If the drop in pressure is less than the initial pressure, the actual discharge will be slightly greater than the quantities given in the table; but this difference will be small for pressures up to 5 pounds, and may be neglected, as it is on the side of safety. For higher initial pressures, Table XV has been prepared. This is to be used in connection with Table XIV as follows: First find from Table XIV the quantity of steam which will be discharged through the given diameter of pipe

TABLE XV

Factors for Calculating Flow of Steam in Pipes under Initial Pressures above Five Pounds

To be used in connection with Table XIV

DROP IN PRESSURE IN POUNDS	INITIAL PRESSURE (POUNDS)					
	10	20	30	40	60	80
¼	1.27	1.49	1.68	1.84	2.13	2.38
½	1.26	1.48	1.66	1.83	2.11	2.36
1	1.24	1.46	1.64	1.80	2.08	2.32
2	1.21	1.41	1.59	1.75	2.02	2.26
3	1.17	1.37	1.55	1.70	1.97	2.20
4	1.14	1.34	1.51	1.66	1.92	2.14
5	1.12	1.31	1.47	1.62	1.87	2.09

TABLE XVI

Factors for Calculating Flow of Steam in Pipes of Other Lengths than 100 Feet

Feet	Factor	Feet	Factor	Feet	Factor	Feet	Factor
10	3.16	120	.91	275	.60	600	.40
20	2.24	130	.87	300	.57	650	.39
30	1.82	140	.84	325	.55	700	.37
40	1.58	150	.81	350	.53	750	.36
50	1.41	160	.79	375	.51	800	.35
60	1.29	170	.76	400	.50	850	.34
70	1.20	180	.74	425	.48	900	.33
80	1.12	190	.72	450	.47	950	.32
90	1.05	200	.70	475	.46	1,000	.31
100	1.00	225	.66	500	.45		
110	.95	250	.63	550	.42		

with the assumed drop in pressure; then look in Table XV for the factor corresponding with the assumed drop and the higher initial pressure to be used. The quantity given in Table XIV, *multiplied by* this factor, will give the actual capacity of the pipe under the given conditions.

Example—What weight of steam will be discharged through a 3-inch pipe 100 feet long, with an initial pressure of 60 pounds and a drop of 2 pounds?

Looking in Table XIV, we find that a 3-inch pipe will discharge 25.4 pounds of steam per minute with a 2-pound drop. Then looking in Table XV, we find the factor corresponding to 60 pounds initial pressure and a drop of 2 pounds to be 2.02. Then according to the rule given, 25.4 × 2.02 = 51.3 pounds, which is the capacity of a 3-inch pipe under the assumed conditions.

Sometimes the problem will be presented in the following way: What size of pipe will be required to deliver 80 pounds of steam a distance of 100 feet with an initial pressure of 40 pounds and a drop of 3 pounds?

We have seen that the higher the initial pressure with a given drop, the greater will be the quantity of steam discharged; therefore a smaller pipe will be required to deliver 80 pounds of steam at 40 pounds than at 3 pounds initial pressure From Table XV, we find that a given pipe will discharge 1.7 times as much steam per minute with a pressure of 40 pounds and a drop of 3 pounds, as it would with a pressure of 3 pounds, dropping to zero. From this it is evident that if we divide 80 by 1.7 and look in Table XIV under "3 pounds drop" for the result thus obtained, the size of pipe corresponding will be that required. Now, 80 ÷ 1.7 = 47. The nearest number in the table marked "3 pounds drop" is 47.8, which corresponds to a 3½-inch pipe, which is the size required.

These conditions will seldom be met with in low-pressure heating, but apply more particularly to combination power and heating plants, and will be taken up more fully under that head. For lengths of pipe other than 100 feet, multiply the quantities given in Table XIV by the factors found in Table XVI.

Example—What weight of steam will be discharged per minute through a 3½-inch pipe 450 feet long, with a pressure of 5 pounds and a drop of ½ pound?

Table XIV, which may be used for all pressures below 10 pounds, gives for a 3½-inch pipe 100 feet long, a capacity of 18.3 pounds for the above conditions. Looking in Table XVI, we find the correction factor for 450 feet to be .47. Then 18.3 × .47 = 8.6 pounds, the quantity of steam which will be discharged if the pipe is 450 feet long.

Examples involving the use of Tables XIV, XV, and XVI in combination, are quite common in practice. The following example will show the method of calculation:

What size of pipe will be required to deliver 90 pounds of steam per minute a distance of 800 feet, with an initial pressure of 80 pounds and a drop of 5 pounds?

Table XVI gives the factor for 800 feet as .35, and Table XV, that for 80 pounds pressure and 5 pounds drop, as 2.09. Then $\frac{90}{.35 \times 2.09} = 123$, which is the equivalent quantity we must look for in Table XIV. We find that a 4-inch pipe will discharge 91.9 pounds, and a 5-inch pipe 163 pounds. A 4½-inch pipe is not commonly carried in stock, and we should probably use a 5-inch in this case, unless it was decided to use a 4-inch and allow a slightly greater drop in pressure. In ordinary heating work, with pressures varying from 2 to 5 pounds, a drop of ¼ pound in 100 feet has been found to give satisfactory results.

In computing the pipe sizes for a heating system by the above methods, it would be a long process to work out the size of each branch separately. Accordingly Table XVII has been prepared for ready use in low-pressure work.

As most direct heating systems, and especially those in schoolhouses, are made up of both radiators and circulation coils, an efficiency of 300 B. T. U. has been taken for direct radiation of whatever variety, no distinction being made between the different kinds. This gives a slightly larger pipe than is necessary for cast-iron radiators; but it is probably offset by bends in the pipes, and in any case gives a slight factor of safety. We find from a steam table that the *latent heat* of steam at 20 pounds above a vacuum (which corresponds to 5 pounds'gauge-pressure) is 954 + B. T. U.—which means that, for every pound of steam condensed in a radiator, 954 B. T. U. are given off for warming the air of the room. If a radiator has an efficiency of 300 B. T. U., then each square foot of surface will condense 300 ÷ 954 = .314 pound of steam per hour; so that we may assume in round numbers a condensation of ⅓ of a pound of steam per hour for each square foot of direct radiation, when computing the sizes of steam pipes in low-pressure heating. Table XVII has been calculated on this assumption, and gives the square feet of heating surface which different sizes of pipe will supply, with drops in pressure of ¼ and ½ pounds in each 100 feet of pipe. The former should be used for pressures from 1 to 5 pounds, and the latter may be used for pressures over 5 pounds, under ordinary conditions. The sizes of long mains and special pipes of large size should be proportioned directly from Tables XIV, XV, and XVI.

TABLE XVII

Heating Surface Supplied by Pipes of Various Sizes

Length of Pipe, 100 Feet

SIZE OF PIPE	SQUARE FEET OF HEATING SURFACE	
	¼ Pound Drop	½ Pound Drop
1	80	114
1¼	145	210
1½	190	340
2	525	750
2½	950	1,350
3	1,550	2,210
3½	2,320	3,290
4	3,250	4,620
5	5,800	8,220
6	9,320	13,200
7	13,800	19,620
8	19,440	27,720

Where the two-pipe system is used and the radiators have separate supply and return pipes, the risers or vertical pipes may be taken from Table XVII; but if the single-pipe system is used, the risers must be increased in size, as the steam and water are flowing in opposite directions and must have plenty of room to pass each other. It is customary in this case to base the computation on the velocity of the steam in the pipes, rather than on the drop in pressure. Assuming, as before, a condensation of one-third of a pound of steam per hour per square foot of radiation, Tables XVIII and XIX have been prepared for velocities of 10 and 15 feet per second. The sizes given in Table XIX have been found sufficient in most cases; but the larger sizes, based on a flow of 10 feet per second, give greater safety and should be more generally used. The size of the largest riser should usually be limited to 2½ inches in school and dwelling-house work, unless it is a special pipe carried up in a concealed position. If the length of riser is short between the lowest radiator and the main, a higher velocity of 20 feet or more may be allowed through this portion, rather than make the pipe excessively large.

TABLE XVIII TABLE XIX

Radiating Surface Supplied by Steam Risers

10 Feet per Second Velocity		15 Feet per Second Velocity	
Size of Pipe	Sq. Feet of Radiation	Size of Pipe	Sq. Feet of Radiation
1 in.	30	1 in.	50
1¼ "	60	1¼ "	90
1½ "	80	1½ "	120
2 "	130	2 "	200
2½ "	190	2½ "	290
3 "	290	3 "	340
3½ "	390	3½ "	590

EXAMPLES FOR PRACTICE

1. How many pounds of steam will be delivered per minute, through a 3½-inch pipe 600 feet long, with an initial pressure of 5 pounds and a drop of ½ pound? Ans. 7.32 pounds.

2. What size pipe will be required to deliver 25.52 pounds of steam per minute with an initial pressure of 3 pounds and a drop of ¼ pound, the length of the pipe being 50 feet? Ans. 4-inch.

3. Compute the size of pipe required to supply 10,000 square feet of direct radiation (assume ⅓ of a pound of steam per square

foot per hour) where the distance to the boiler house is 300 feet, and the pressure carried is 10 pounds, allowing a drop in pressure of 4 pounds. Ans. 5-inch (this is slightly larger than is required, while a 4-inch is much too small).

TABLE XX
Sizes of Returns for Steam Pipes (in Inches)

DIAMETER OF STEAM PIPE	DIAMETER OF DRY RETURN	DIAMETER OF SEALED RETURN
1	1	¾
1¼	1	1
1½	1¼	1
2	1½	1¼
2½	2	1½
3	2¼	2
3½	2½	2
4	3	2½
5	3	2½
6	3½	3
7	3½	3
8	4	3½
9	5	3½
10	5	4
12	6	5

Returns. The size of return pipes is usually a matter of custom and judgment rather than computation. It is a common rule among steamfitters to make the returns one size smaller than the corresponding steam pipes. This is a good rule for the smaller sizes, but gives a larger return than is necessary for the larger sizes of pipe. Table XX gives different sizes of steam pipes with the corresponding diameters for dry and sealed returns.

TABLE XXI
Pipe Sizes for Radiator Connections

SQUARE FEET OF RADIATION		STEAM	RETURN
Two-Pipe	10 to 30 30 to 48 48 to 96 96 to 150	¾ inch 1 " 1¼ " 1½ "	¾ inch ¾ " 1 " 1¼ "
Single-Pipe	10 to 24 24 to 60 60 to 80 80 to 130	1 inch 1¼ " 1½ " 2 "	

The length of run and number of turns in a return pipe should be noted, and any unusual conditions provided for. Where the condensation is discharged through a trap into a lower pressure, the sizes given may be slightly reduced, especially among the larger sizes, depending upon the differences in pressure.

Radiators are usually tapped for pipe connections as shown in Table XXI, and these sizes may be used for the connections with the mains or risers.

Boiler Connections. The steam main should be connected to the rear nozzle, if a tubular boiler is used, as the boiling of the water is less violent at this point and dryer steam will be obtained. The shut-off valve should be placed in such a position that pockets for the accumulation of condensation will be avoided. Fig. 47 shows a good position for the valve.

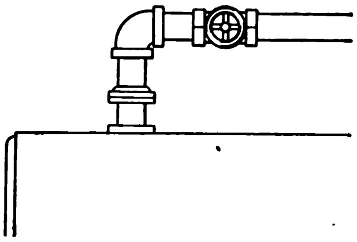


Fig 47. Good Position for Shut-Off Valve.

The size of steam connection may be computed by means of the methods already given, if desired. But for convenience the sizes given in Table XXII may be used with satisfactory results for the short runs between the boilers and main header.

TABLE XXII
Pipe Sizes from Boiler to Main Header

Diameter of Boiler	Size of Steam Pipe
36 inches	3 inches
42 "	4 "
48 "	4 "
54 "	5 "
60 "	5 "
66 "	6 "
72 "	6 "

The return connection is made through the blow-off pipe, and should be arranged so that the boiler can be blown off without draining the returns. A check-valve should be placed in the main return, and a plug-cock in the blow-off pipe. Fig. 48 shows in plan a good arrangement for these connections.

The feed connections, with the exception of that part exposed in the smoke-bonnet, are always made of brass in the best class of work. The small section referred to should be of extra heavy wrought iron. The branch to each boiler should be provided with a gate or globe valve and a check-valve, the former being placed next to the boiler.

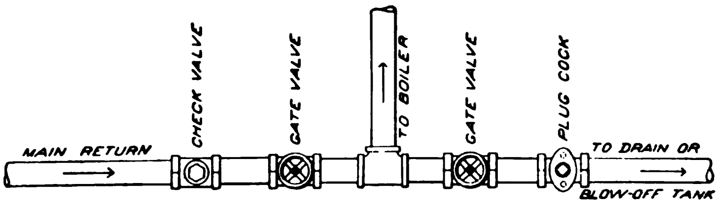


Fig. 48. A Good Arrangement of Return and Blow-Off Connections.

Table XXIII gives suitable sizes for return, blow-off, and feed pipes for boilers of different diameters.

TABLE XXIII

Sizes for Return, Blow-Off, and Feed Pipes

Diameter of Boiler	Size of Pipe for Gravity Return	Size of Blow-Off Pipe	Size of Feed Pipe
36 inches	1½ inches	1¼ inches	1 inch
42 "	2 "	1½ "	1 "
48 "	2 "	1½ "	1 "
54 "	2½ "	2 "	1¼ "
60 "	2½ "	2 "	1¼ "
66 "	3 "	2½ "	1½ "
72 "	3 "	2½ "	1½ "

Blow-Off Tank. Where the blow-off pipe connects with a sewer, some means must be provided for cooling the water, or the expansion and contraction caused by the hot water flowing through the drain-pipes will start the joints and cause leaks. For this reason it is customary to pass the water through a blow-off tank. A form of wrought-iron tank is shown in Fig. 49. It consists of a receiver supported on cast-iron cradles. The tank ordinarily stands nearly full of cold water.

The pipe from the boiler enters above the water-line, and the sewer connection leads from near the bottom, as shown. A vapor pipe is carried from the top of the tank above the roof of the building. When water from the boiler is blown into the tank, cold water from the bottom flows into the sewer, and the steam is carried off through the vapor pipe. The equalizing pipe is to prevent any siphon action which might draw the water out of the tank after a flow is once started. As only a part of the water is blown out of a boiler at one time, the blow-off tank can be of a comparatively small size. A tank 24 by 48 inches should be large enough for boilers up to 48 inches in diameter; and one 36 by 72 inches should care for a boiler 72 inches in diameter. If smaller quantities of water are blown off at one time, smaller tanks can be used. The sizes given above are sufficient for batteries of 2 or more boilers, as one boiler can be blown off and the water allowed to cool before a second one is blown off. Cast-iron tanks are often used in place of wrought-iron, and these may be sunk in the ground if desired.

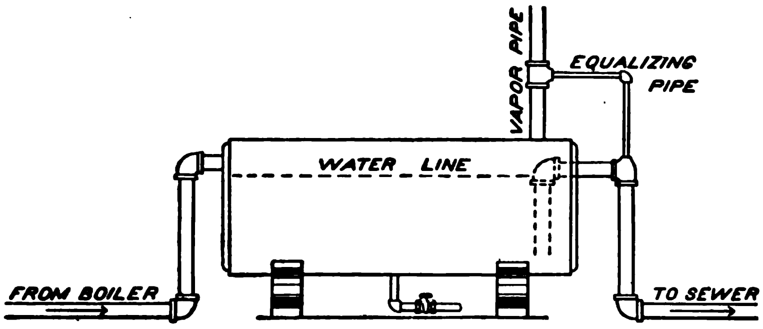
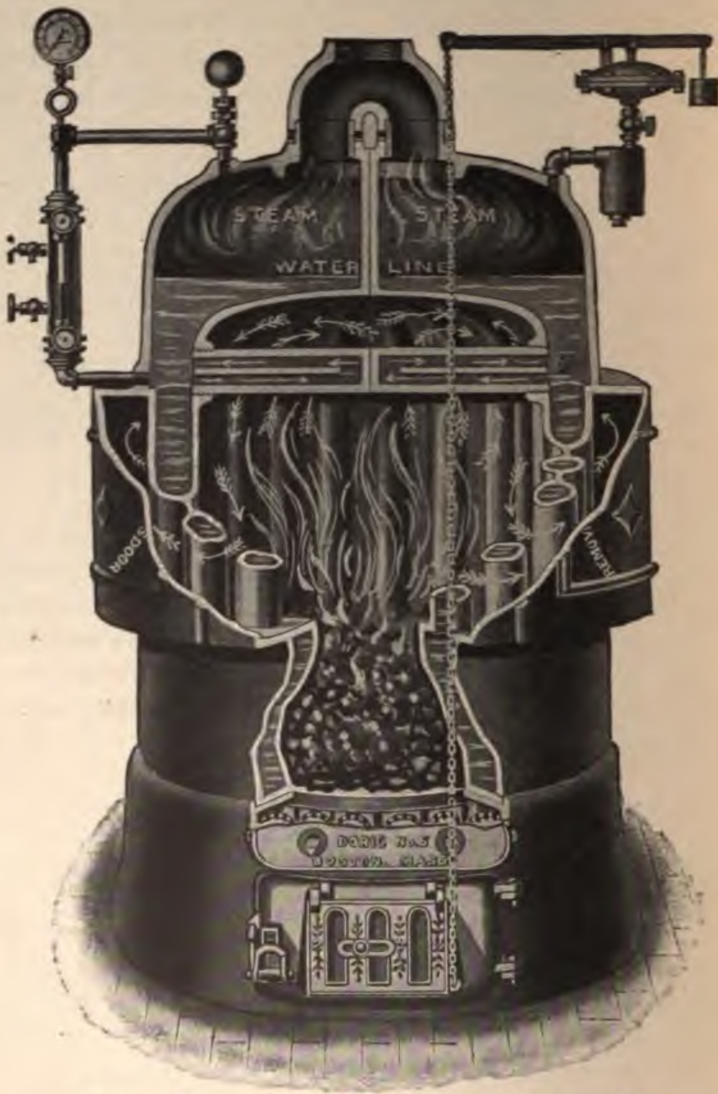


Fig. 49. Connections of Blow-Off Tank.



Cast Iron Seamless Tubular Steam Heater.

HEATING AND VENTILATION

PART II

INDIRECT STEAM HEATING

As already stated, in the indirect method of steam heating, a special form of heater is placed beneath the floor, and encased in galvanized iron or in brickwork. A cold-air box is connected with the space beneath the heater; and warm-air pipes at the top are connected with registers in the floors or walls as already described for furnaces. A separate heater may be provided for each register if the rooms are large, or two or more registers may be connected with the same heater if the horizontal runs of pipe are short. Fig. 50 shows a section through a heater arranged for introducing hot air into a room through a floor register; and Fig. 51 shows the same type of heater connected with a wall register. The cold-air box is seen at the bottom of the casing; and the air, in passing through the spaces between the sections of the heater, becomes warmed, and rises to the rooms above.

Different forms of indirect heaters are shown in Figs. 52 and 53. Several sections connected in a single group are called a *stack*. Sometimes the stacks are encased in brickwork built up from the basement floor, instead of in galvanized iron as shown in the cuts. This method of heating provides fresh air for ventilation, and for this reason is especially adapted for schoolhouses, hospitals, churches, etc. As compared with furnace heating, it has the advantage of being less affected by outside wind-pressure, as long runs of horizontal pipe

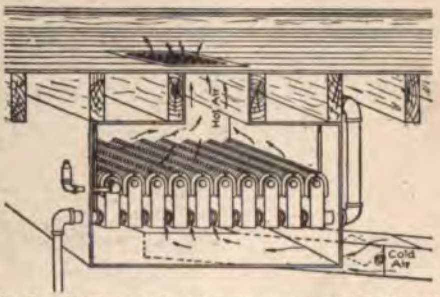


Fig. 50. Steam Heater Placed under Floor Register —Indirect System.

are avoided and the heaters can be placed near the registers. In a large building where several furnaces would be required, a single boiler can be used, and the number of stacks increased to suit the existing conditions, thus making it necessary to run but a single fire. Another advantage is the large ratio between the heating and grate surface as compared with a furnace; and as a result, a large quantity of air is warmed to a moderate temperature, in place of a smaller quantity heated to a much higher temperature. This gives a more agreeable quality to the air, and renders it less dry. Direct and indirect systems are often combined, thus providing the living rooms with ventilation, while the hallways, corridors, etc., have only direct radiators for warming.

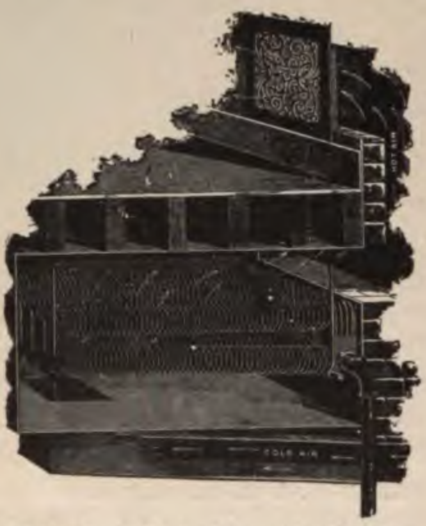


Fig. 51. Steam Heater Connected to Wall Register.—Indirect System.

Types of Heaters. Various forms of indirect radiators are shown in Figs. 52, 53, 54, and 56. A hot-water radiator may be used for steam; but a steam radiator cannot always be used for hot water, as it must be especially designed to produce a continuous flow of water through it from top to bottom. Figs. 54 and 55 show the outside and the interior construction of a common pattern of indirect radiator

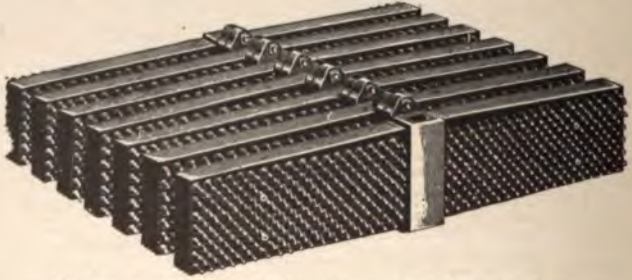


Fig. 52. One Form of Indirect Steam or Hot-Water Heater.

designed especially for steam. The arrows in Fig. 55 indicate the path of the steam through the radiator, which is supplied at the right, while the return connection is at the left. The air-valve in this case should be connected in the end of the last section near the return.

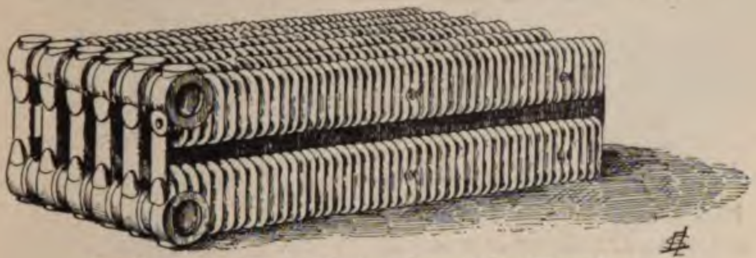


Fig. 53. Another Form of Indirect Steam or Hot-Water Heater.

A very efficient form of radiator, and one that is especially adapted to the warming of large volumes of air, as in schoolhouse work, is shown in Fig. 56, and is known as the *School pin* radiator. This can be used for either steam or hot water, as there is a continuous passage downward from the supply connection at the top to the return at the bottom. These sections or slabs are made up in stacks after the manner shown in Fig. 57, which represents an end view of several sections connected together with special nipples.

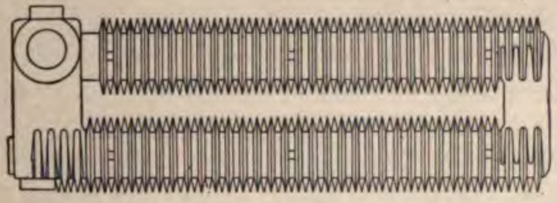


Fig. 54. Exterior View of a Common Type of Radiator for Indirect-Steam Heating.

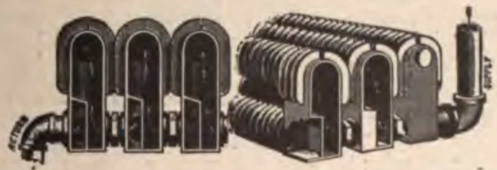


Fig. 55. Interior Mechanism of Radiator Shown in Fig. 54.

A very efficient form of indirect heater may be made up of wrought-iron pipe joined together with branch tees and return bends.

A heater like that shown in Fig. 58 is known as a *box coil.* Its efficiency is increased if the pipes are *staggered*—that is, if the pipes in alternate rows are placed over the spaces between those in the row below.

Efficiency of Heaters. The efficiency of an indirect heater depends upon its form, the difference in temperature between the steam and the surrounding air, and the velocity with which the air passes over the heater. Under ordinary conditions in dwelling-house work, a good form of indirect radiator will give off about 2 B. T. U. per square foot per hour for each degree difference in temperature between the steam and the entering air. Assuming a steam pressure of 2 pounds and an outside temperature of zero, we should have a difference in temperature of about 220 degrees, which, under the conditions stated, would give an efficiency of 220 × 2 = 440 B. T. U. per hour for each square foot of radiation. By making a similar computation for 10 degrees below zero, we find the efficiency to be 460. In the same manner we may calculate the efficiency for varying conditions of steam pressure and outside temperature. In the case of schoolhouses and similar buildings where large volumes of air are warmed to a moderate tem-

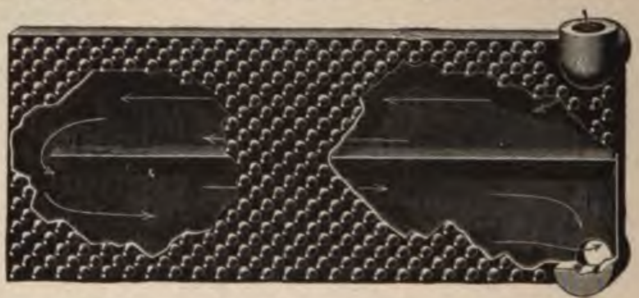


Fig. 56. "School Pin" Radiator, Especially Adapted for Warming Large Volumes of Air by Either Steam or Hot Water.

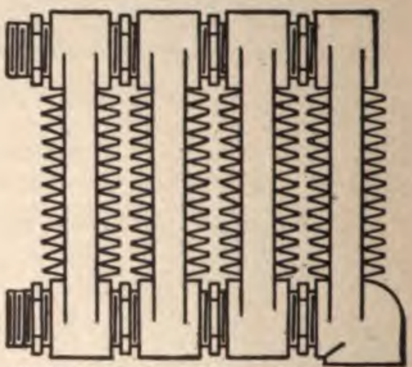


Fig. 57. End View of Several "School Pin" Radiator Sections Connected Together.

perature, a somewhat higher efficiency is obtained, owing to the increased velocity of the air over the heaters. Where efficiencies of 440 and 460 are used for dwellings, we may substitute 600 and 620 for schoolhouses. This corresponds approximately to 2.7 B. T. U. per square foot per hour for a difference of 1 degree between the air and steam.

The principles involved in indirect steam heating are similar to those already described in furnace heating. Part of the heat given off by the radiator must be used in warming up the air-supply to the temperature of the room, and part for offsetting the loss by conduction through walls and windows. The method of computing the heating surface required, depends upon the volume of air to be supplied to the room. In the case of a schoolroom or hall, where the air quantity is large as compared with the exposed wall and window surface, we should proceed as follows:

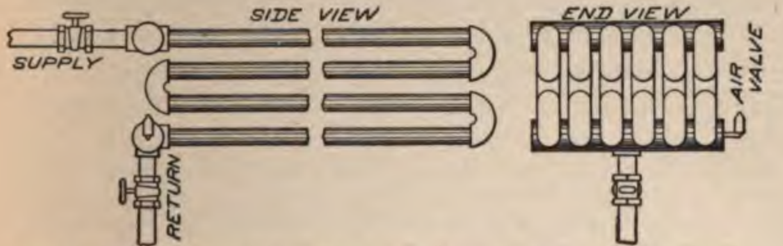


Fig. 58. "Box Coil," Built Up of Wrought-Iron Pipe, for Indirect-Steam Heating.

First compute the B. T. U. required for loss by conduction through walls and windows; and to this, add the B. T. U. required for the necessary ventilation; and divide the sum by the efficiency of the radiators. An example will make this clear.

Example. How many square feet of indirect radiation will be required to warm and ventilate a schoolroom in zero weather, where the heat loss by conduction through walls and windows is 36,000 B. T. U., and the air-supply is 100,000 cubic feet per hour?

By the methods given under "Heat for Ventilation," we have

$$\frac{100{,}000 \times 70}{55} \times 127{,}272 = \text{B. T. U. required for ventilation.}$$

$$36{,}000 + 127{,}272 = 163{,}272 \text{ B. T. U.} = \text{Total heat required.}$$

This in turn divided by 600 (the efficiency of indirect radiators under these conditions) gives 272 square feet of surface required.

In the case of a dwelling-house the conditions are somewhat changed, for a room having a comparatively large exposure will have perhaps only 2 or 3 occupants, so that, if the small air-quantity necessary in this case were used to convey the required amount of heat to the room, it would have to be raised to an excessively high temperature. It has been found by experience that the radiating surface necessary for indirect heating is about 50 per cent greater than that required for direct heating. So for this work we may compute the surface required for direct radiation, and multiply the result by 1.5.

Buildings like hospitals are in a class between dwellings and schoolhouses. The air-supply is based on the number of occupants, as in schools, but other conditions conform more nearly to dwelling-houses.

To obtain the radiating surface for buildings of this class, we compute the total heat required for warming and ventilation as in the case of schoolhouses, and divide the sum by the efficiencies given for dwellings—that is, 440 for zero weather, and 460 for 10 degrees below.

Example. A hospital ward requires 50,000 cubic feet of air per hour for ventilation; and the heat loss by conduction through walls, etc., is 100,000 B. T. U. per hour. How many square feet of indirect radiation will be required to warm the ward in zero weather?

50,000 × 70 ÷ 55 = 63,636 B. T. U. for ventilation; then,

$$\frac{63{,}636 + 100{,}000}{440} = 372 + \text{ square feet.}$$

EXAMPLES FOR PRACTICE

1. A schoolroom having 40 pupils is to be warmed and ventilated when it is 10 degrees below zero. If the heat loss by conduction is 30,000 B. T. U. per hour, and the air supply is to be 40 cubic feet per minute per pupil, how many square feet of indirect radiation will be required? Ans. 273.

2. A contagious ward in a hospital has 10 beds, requiring 6,000 cubic feet of air each, per hour. The heat loss by conduction in zero weather is 80,000 B. T. U. How many square feet of indirect radiation will be required? Ans. 355.

3. The heat loss from a sitting room is 11,250 B. T. U. per hour in zero weather. How many square feet of indirect radiation will be required to warm it? Ans. 75.

Stacks and Casings. It has already been stated that a group of sections connected together is called a stack, and examples of these with their casings are shown in Figs. 50 and 51. The casings are usually made of galvanized iron, and are made up in sections by means of small bolts so that they may be taken apart in case it is necessary to make repairs. Large stacks are often enclosed in brickwork, the sides consisting of 8-inch walls, and the top being covered over with a layer of brick and mortar supported on light wrought-iron tee-bars. Blocks of asbestos are sometimes used for covering, instead of brick, the whole being covered over with plastic material of the same kind.

Where a single stack supplies several flues or registers, the connections between these and the warm-air chamber are made in the same manner as already described for furnace heating. When galvanized-iron casings are used, the heater is supported by hangers from the floor above. Fig. 59 shows the method of hanging a heater from a wooden floor. If the floor is of fireproof construction, the hangers may pass up through the brickwork, and the ends be provided with nuts and large washers or plates; or they may be clamped to the iron beams which carry the floor. Where brick casings are used, the heaters are supported upon pieces of pipe or light I-beams built into the walls.

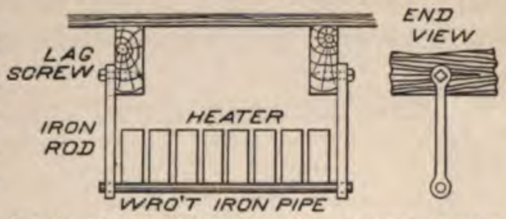


Fig. 59. Method of Hanging a Heater below a Wooden Floor.

The warm-air space above the heater should never be less than 8 inches, while 12 inches is preferable for heaters of large size. The cold-air space may be an inch or two less; but if there is plenty of room, it is good practice to make it the same as the space above.

Dampers. The general arrangement of a galvanized-iron casing and mixing damper is shown in Fig. 60. The cold-air duct is brought along the basement ceiling from the inlet window, and connects with the cold-air chamber beneath the heater. The entering air passes up between the sections, and rises through the register above, as shown by the arrows. When the mixing damper is in its lowest position, all air reaching the register must pass through the heater; but if the damper is raised to the position shown, part of the air will pass by without going through the heater, and the mixture entering through the register will be at a lower temperature than before. By changing the position of the damper, the proportions of warm and cold air delivered to the room can be varied, thus regulating the temperature without diminishing to any great extent the quantity of air delivered.

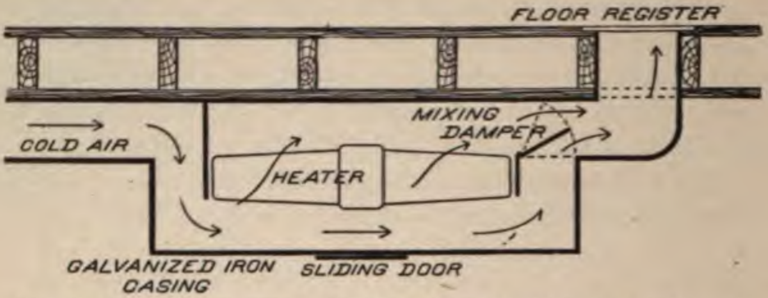


Fig. 60. General Arrangement of a Galvanized-Iron Casing and Mixing Damper. Damper between Heater and Register.

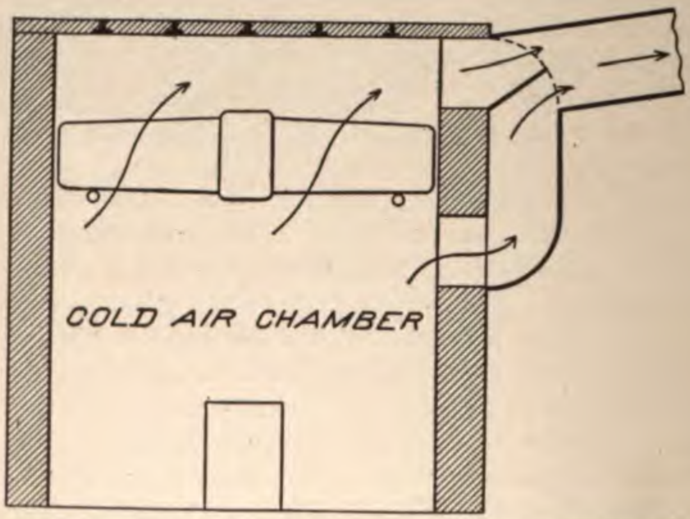


Fig. 61. Heater and Mixing Damper with Brick Casing. Damper between Heater and Register.

The objection to this form of damper is that there is a tendency for the air to enter the room before it is thoroughly mixed; that is, a stream of warm air will rise through one half of the register while cold air enters through the other. This is especially true if the connection between the damper and register is short. Fig. 61 shows a similar heater and mixing damper, with brick casing. Cold air is admitted to the large chamber below the heater, and rises through the sections to the register as before. The action of the mixing damper is the same as already described. Several flues or registers may be connected with a stack of this form, each connection having, in addition to its mixing damper, an adjusting damper for regulating the flow of air to the different rooms.

Another way of proportioning the air-flow in cases of this kind is to divide the hot-air chamber above the heater into sections, by means of galvanized-iron partitions, giving to each room its proper share of heating surface. If the cold-air supply is made sufficiently large, this arrangement is preferable to using adjusting dampers as described above. The partitions should be carried down the full depth of the heater between the sections, to secure the best results.

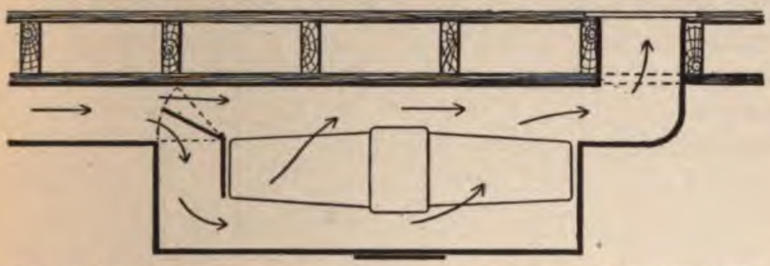


Fig. 62. Another Arrangement of Mixing Damper and Heater in Galvanized-Iron Casing. Heater between Damper and Register.

The arrangement shown in Fig. 62 is somewhat different, and overcomes the objection noted in connection with Fig. 60, by substituting another. The mixing damper in this case is placed at the other end of the heater. When it is in its highest position, all of the air must pass through the heater before reaching the register; but when partially lowered, a part of the air passes over the heater, and the result is a mixture of cold and warm air, in proportions depending upon the position of the damper. As the layer of warm air in this case is below the cold air, it tends to rise through it, and a more thorough mixture is obtained than is possible with the damper shown in Fig. 60. One quite serious objection, however, to this form of damper, is illustrated in Fig. 63. When the damper is nearly closed so that the greater part of the air enters above the heater, it has a tendency to fall between the sections, as shown by the arrows, and, becoming heated, rises again, so that it is impossible to deliver air to a room below a certain temperature. This peculiar action increases as the quantity of air admitted below the heater is diminished. When the inlet register is placed in the wall at some distance above the floor, as in schoolhouse work, a thorough mixture of air can be obtained by placing the heater so that the current of warm air will pass up the front of the flue and be discharged into the room through the lower part of the register. This is shown quite clearly in Fig. 64, where the current of warm air is represented by crooked arrows, and the cold air by straight arrows. The two currents pass up the flue separately; but as soon as they are discharged through the register the warm air tends to rise, and the cold air to fall, with the result of a more or less complete mixture, as shown.

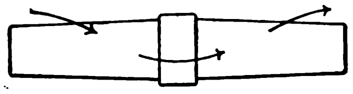


Fig. 63. Showing Difficulty of Regulating Temperature with Arrangement in Fig. 62.

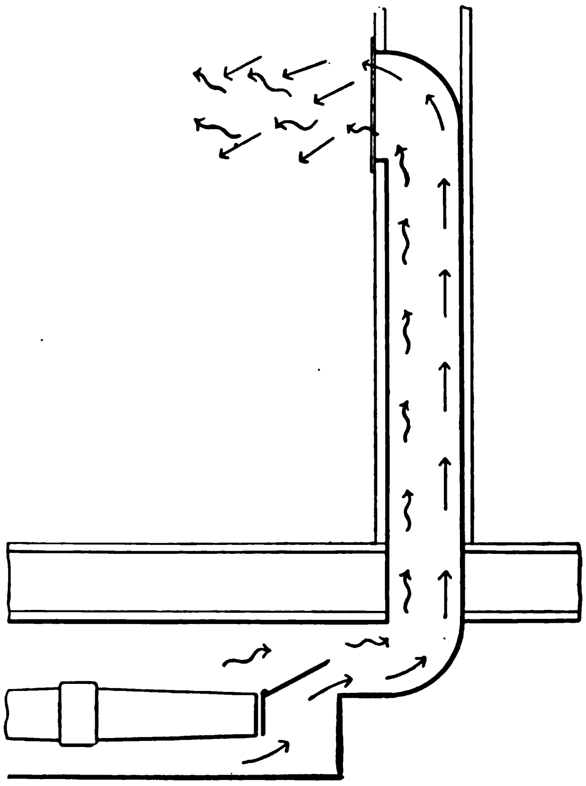


Fig. 64. Arrangement of Heater and Damper Causing Warm Air to Enter Room through Lower Part of Register, thus Securing Thorough Mixing

It is often desirable to warm a room at times when ventilation is not necessary, as in the case of living rooms during the night, or for quick warming in the morning. A register and damper for air rotation should be provided in this case. Fig. 65 shows an arrangement for this purpose. When the damper is in the position shown, air will be taken from the room above and be warmed over and over; but, by raising the damper, the supply will be taken from outside. Special care should be taken to make all mixing dampers tight against air-leakage, else their advantages will be lost. They should work easily and close tightly against flanges covered with felt. They may be operated from the rooms above by means of chains passing over guide-pulleys; special attachments should be provided for holding in any desired position.

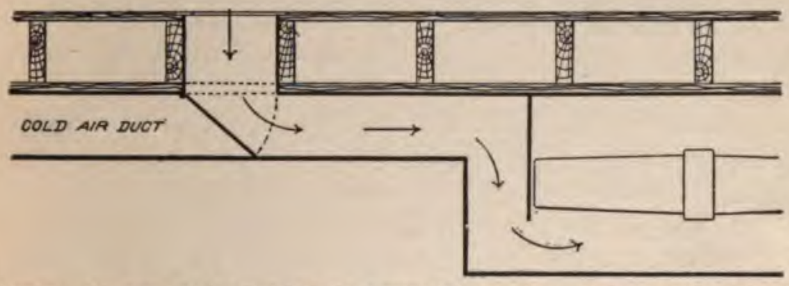


Fig. 65. Arrangement for Quick Heating without Ventilation. Damper Shuts off Fresh Air, and Air of Room Heated by Rotating Forth and Back through Register and Heater.

Warm-Air Flues. The required size of the warm-air flue between the heater and the register, depends first upon the difference in temperature between the air in the flue and that of the room, and second, upon the height of the flue. In dwelling-houses, where the conditions are practically constant, it is customary to allow 2 square inches area for each square foot of radiation when the room is on the first floor, and 1½ square inches for the second and third floors. In the case of hospitals, where a greater volume of air is required, these figures may be increased to 3 square inches for the first floor wards, and 2 square inches for those on the upper floors.

In schoolhouse work, it is more usual to calculate the size of flue from an assumed velocity of air-flow through it. This will vary greatly according to the outside temperature and the prevailing wind conditions. The following figures may be taken as average velocities obtained in practice, and may be used as a basis for calculating the required flue areas for the different stories of a school building:

1st floor, 280 feet per minute.
2nd " , 340 " " "
3rd " , 400 " " "

These velocities will be increased somewhat in cold and windy weather and will be reduced when the atmosphere is mild and damp.

Having assumed these velocities, and knowing the number of cubic feet of air to be delivered to the room per minute, we have only to divide this quanity by the assumed velocity, to obtain the required flue area in square feet.

Example. A schoolroom on the second floor is to have an air-supply of 2,000 cubic feet per minute. What will be the required flue area?

Ans. 2000 ÷ 340 = 5.8 + sq. feet.

The velocities would be higher in the coldest weather, and dampers should be placed in the flues for throttling the air-supply when necessary.

Cold-Air Ducts. The cold-air ducts supplying heaters should be planned in a manner similar to that described for furnace heating. The air-inlet should be on the north or west side of the building; but this of course is not always possible. The method of having a large trunk line or duct with inlets on two or more sides of the building, should be carried out when possible. A cold-air room with large inlet windows, and ducts connecting with the heaters, makes a good arrangement for schoolhouse work. The inlet windows in this case should be provided with check-valves to prevent any outward flow of air. A detail of this arrangement is shown in Fig. 66.

This consists of a boxing around the window, extending from the floor to the ceiling. The front is sloped as shown, and is closed from the ceiling to a point below the bottom of the window. The remainder is open, and covered with a wire netting of about ½-inch mesh; to this are fastened flaps or checks of gossamer cloth about 6 inches in width. These are hemmed on both edges and a stout wire is run through the upper hem which is fastened to the netting by means of small copper or soft iron wire. The checks allow the air to flow inward but close when there is any tendency for the current to reverse.

The area of the cold-air duct for any heater should be about three-fourths the total area of the warm-air ducts leading from it.

If the duct is of any considerable length or contains sharp bends, it should be made the full size of all the warm-air ducts. Adjusting dampers should be placed in the supply duct to each separate stack. If a trunk with two inlets is used, each inlet should be of sufficient size to furnish the full amount of air required, and should be provided with cloth checks for preventing an outward flow of air, as already described. The inlet windows should be provided with some form of damper or slide, outside of which should be placed a wire grating, backed by a netting of about ⅜-inch mesh.

Vent Flues. In dwelling-houses, vent flues are often omitted, and the frequent opening of doors and leakage are depended upon to carry away the impure air. A well-designed system of warming should provide some means for discharge ventilation, especially for bathrooms and toilet-rooms, and also for living rooms where lights are burned in the evening. Fireplaces are usually provided in the more important rooms of a well-built house, and these are made to serve as vent flues. In rooms having no fireplaces, special flues of tin or galvanized iron may be carried up in the partitions in the same manner as the warm-air flues. These should be gathered together in the attic, and connected with a brick flue running up beside the boiler or range chimney.

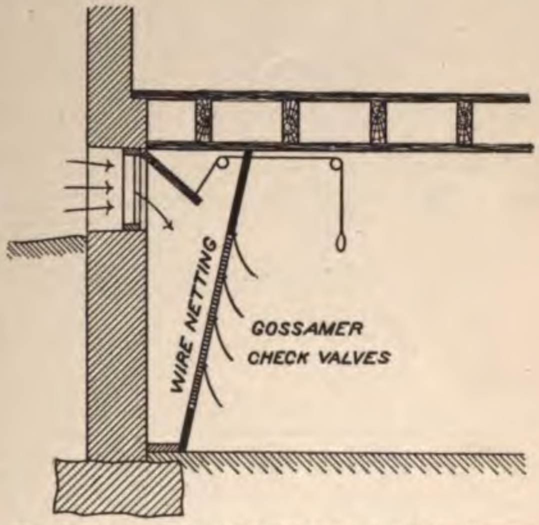


Fig. 66. Air-Inlet Provided with Check-Valves to Prevent Outward Flow of Air.

Very fair results may be obtained by simply letting the flues open into an unfinished attic, and depending upon leakage through the roof to carry away the foul air.

The sizes of flues may be made the reverse of the warm-air flues —that is, 1½ square inches area per square foot of indirect radiation for rooms on the first floor, and 2 square inches for those on the second. This is because the velocity of flow will depend upon the height of flue, and will therefore be greater from the first floor. The flow of air through the vents will be slow at best, unless some means is provided for warming the air in the flue to a temperature above that of the room with which it connects.

The method of carrying up the outboard discharge beside a warm chimney is usually sufficient in dwelling-houses; but when it is desired to move larger quantities of air, a loop of steam pipe should be run inside the flue. This should be connected for drainage and air-venting as shown in Fig. 67. When vents are carried through the roof independently, some form of protecting hood should be provided for keeping out the snow and rain. A simple form is shown in Fig. 68. Flues carried outboard in this way should always be extended well above the ridges of adjacent roofs to prevent down drafts in windy weather.

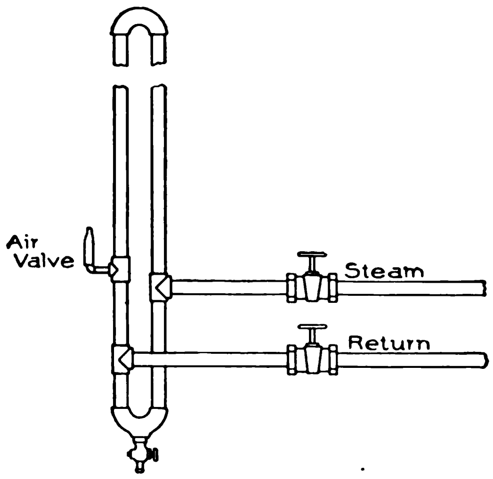


Fig. 67. Loop of Steam Pipe to be Run Inside Flue. Connected for Drainage and Air-Venting.

For schoolhouse work we may assume average velocities through the vent flues, as follows:

1st floor, 340 feet per minute.
2nd " , 280 " " "
3rd " , 220 " " "

Where flue sizes are based on these velocities, it is well to guard against down drafts by placing an aspirating coil in the flue. A single row of pipes across the flue as shown in Fig. 69, is usually sufficient for this purpose when the flues are large and straight;

otherwise, two rows should be provided. The slant height of the heater should be about twice the depth of the flue, so that the area between the pipes shall equal the free area of the flue.

Large vent flues of this kind should always be provided with dampers for closing at night, and for regulation during strong winds.

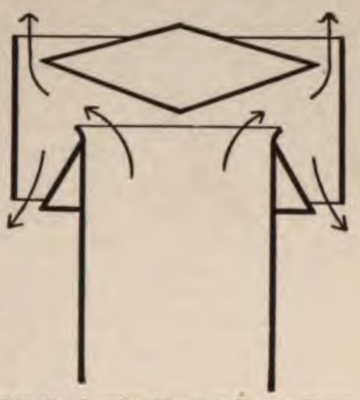


Fig. 68. Section Showing Simple Form of Protecting Hood for Vent Carried through Roof.

Sometimes it is desired to move a given quantity of air through a flue which is already in place. Table XXIV shows what velocities may be obtained through flues of different heights, for varying differences in temperature between the outside air and that in the flue.

Example.—It is desired to discharge 1,300 cubic feet of air per minute through a flue having an area of 4 square feet and a height of 30 feet. If the efficiency of an aspirating coil is 400 B. T. U., how many square feet of surface will be required to move this amount of air when the temperature of the room is 70° and the outside temperature is 60°?

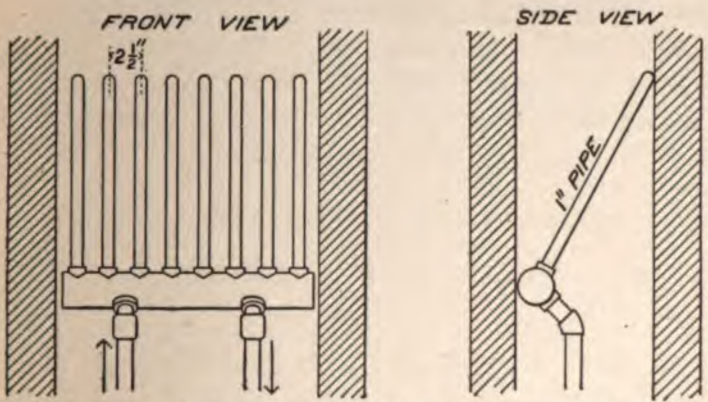


Fig. 69. Aspirating Coil Placed in Flue to Prevent Down Drafts.

1,300 ÷ 4 = 325 feet per minute = Velocity through the flue. Looking in Table XXIV, and following along the line opposite a 30-foot flue, we find that to obtain this velocity there must be a difference of 30 degrees between the air in the flue and the external air.

If the outside temperature is 60 degrees, then the air in the flue must be raised to 60 + 30 = 90 degrees. The air of the room being at 70 degrees, a rise of 20 degrees is necessary. So the problem resolves itself into the following: What amount of heating surface having an efficiency of 400 B. T. U. is necessary to raise 1,300 cubic feet of air per minute through 20 degrees?

TABLE XXIV

Air-Flow through Flues of Various Heights under Varying Conditions of Temperature

(Volumes given in cubic feet per square foot of sectional area of flue)

HEIGHT OF FLUE IN FEET	EXCESS OF TEMPERATURE OF AIR IN FLUE ABOVE THAT OF EXTERNAL AIR					
	5°	10°	15°	20°	30°	50°
5	55	76	94	109	134	167
10	77	108	133	153	188	242
15	94	133	162	188	230	297
20	108	153	188	217	265	342
25	121	171	210	242	297	383
30	133	188	230	265	325	419
35	143	203	248	286	351	453
40	153	217	265	306	375	484
45	162	230	282	325	398	514
50	171	242	297	342	419	541
60	188	264	325	373	461	594

1,300 cubic feet per minute = 1,300 × 60 = 78,000 per hour; and making use of our formula for "heat for ventilation," we have

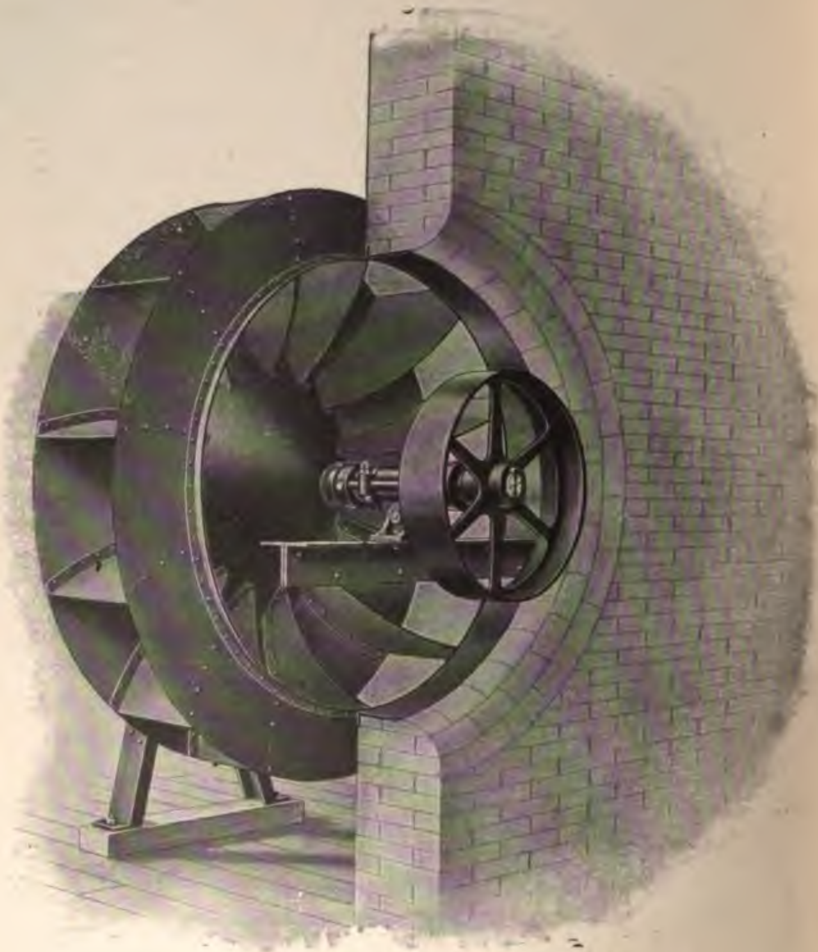
$$\frac{78{,}000 \times 20}{55} = 28{,}363 \text{ B. T. U.};$$

and this divided by 400 = 71 square feet of heating surface required.

EXAMPLES FOR PRACTICE

1. A schoolroom on the third floor has 50 pupils, who are to be furnished with 30 cubic feet of air per minute each. What will be the required areas in square feet of the supply and vent flues?
ANS. Supply, 3.7 +. Vent, 6.8 +.

2. What size of heater will be required in a vent flue 40 feet high and with an area of 5 square feet, to enable it to discharge 1,530 cubic feet per minute, when the outside temperature is 60°? (Assume an efficiency of 400 B. T. U. for the heater.) ANS. 41.7 square feet.



CONE EXHAUST FAN, INLET SIDE.
American Blower Co.

Registers. Registers are made of cast iron and bronze, in a great variety of sizes and patterns. The almost universal finish for cast-iron registers is black "Japan;" but they are also finished in colors and electroplated with copper and nickel. Fig. 70 shows a section through a floor register, in which *A* represents the valves, which may be turned in a vertical or horizontal position, thus opening or closing the register; *B* is the iron border; *C*, the register box of tin or galvanized iron; and *D*, the warm-air pipe. Floor registers are usually set in cast-iron borders, one of which is shown in Fig. 71; while wall registers may be screwed directly to wooden borders or frames to correspond with the finish of the room. Wall registers should be provided with pull-cords for opening and closing from the floor; these are shown in Fig. 72. The plain lattice pattern shown in Fig. 73 is the best for schoolhouse work, as it has a comparatively free opening for air-flow and is pleasing and simple in design. More elaborate patterns are used for fine dwelling-house work. Registers with shut-off valves are used for air-inlets, while the plain register faces without the valves are placed in the vent openings. The vent flues are usually gathered together in the attic, and a single damper may be used to shut off the whole number at once. Flat or round wire gratings of open pattern are often used in place of

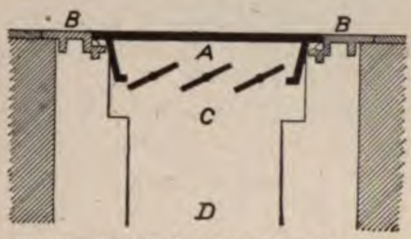


Fig. 70. Section through a Floor Register.

Fig. 71. Cast-Iron Border for a Floor Register.

register faces. The grill or solid part of a register face usually takes up about ⅓ of the area; hence in computing the size, we must allow for this by multiplying the required "net area" by 1.5, to obtain the "total" or "over-all" area.

Example. Suppose we have a flue 10 inches in width and wish to use a register having a free area of 200 square inches. What will be the required height of the register?

$200 \times 1.5 = 300$ square inches, which is the total area required; then $300 \div 10 = 30$, which is the required height, and we should use a 10 by 30-inch register. When a register is spoken of as a 10 by 30-inch or a 10 by 20-inch, etc., the dimensions of the latticed opening are meant, and not the outside dimensions of the whole register. The free opening should have the same area as the flue with which it connects. In designing new work, one should provide himself with a trade catalogue, and use only standard sizes, as special patterns and sizes are costly. Fig. 74 shows the method of placing gossamer check-valves back of the ve[illegible] register faces to prevent down drafts, the same as described [illegible]r fr[illegible]r inlets.

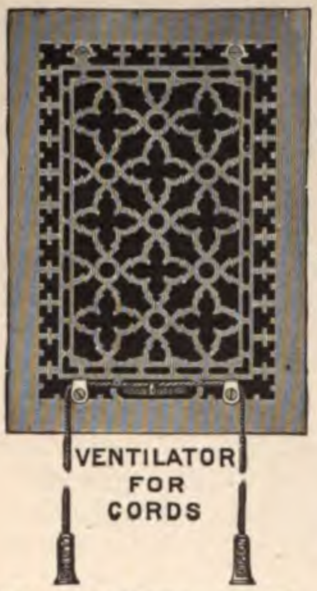


Fig. 72. Wall Register with Pull Cords for Opening and Closing.

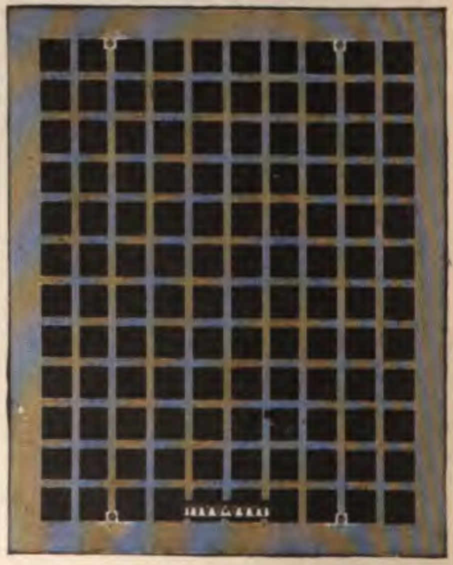


Fig. 73. Plain Lattice Pattern Register. Best for Schoolhouse Work.

Inlet registers in dwelling-house and similar work are placed either in the floor or in the baseboard; sometimes they are located under the windows, just above the baseboard. The object in view is to place them where the currents of air entering the room will not be objectionable to persons sitting near windows. A long, narrow floor-register placed close to the wall in front of a window, sends up a shallow current of warm air, which is not especially noticeable to one sitting near it. Inlet registers are preferably placed near outside walls, especially in large rooms. Vent registers should be placed in inside walls, near the floor.

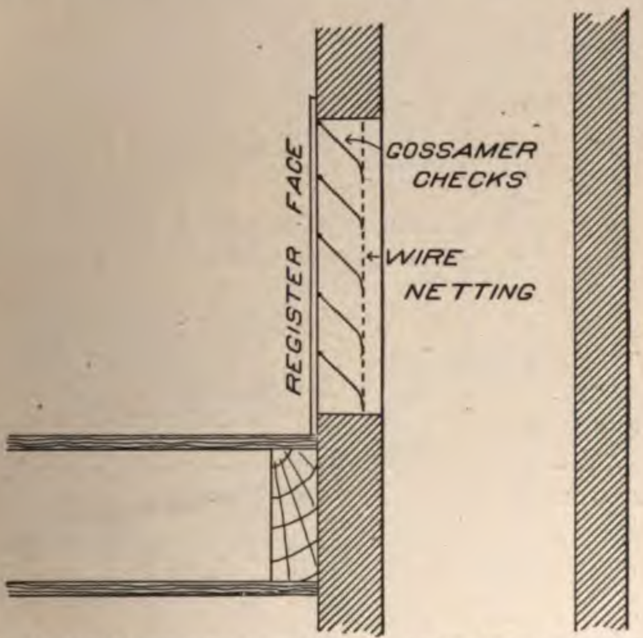


Fig. 74. Method of Placing Gossamer Check-Valves back of Vent Register Face to Prevent Down Drafts.

Pipe Connections. The two-pipe system with dry or sealed returns is used in indirect heating. The conditions to be met are practically the same as in direct heating, the only difference being that the radiators are at the basement ceiling instead of on the floors above. The exact method of making the pipe connections will depend somewhat upon existing conditions; but the general method shown in Fig. 75 may be used as a guide, with modifications to suit any special case. The ends of all supply mains should be dripped, and the horizontal returns should be sealed if possible.

Pipe Sizes. The tables already given for the proportioning of pipe sizes can be used for indirect systems. The following table has been computed for an efficiency of 640 B. T. U. per square foot of surface per hour, which corresponds to a condensation of $\frac{2}{3}$ of a pound of steam. This is twice that allowed for direct radiation in Table XVII; so that we can consider 1 square foot of indirect surface as equal to 2 of direct in computing pipe sizes.

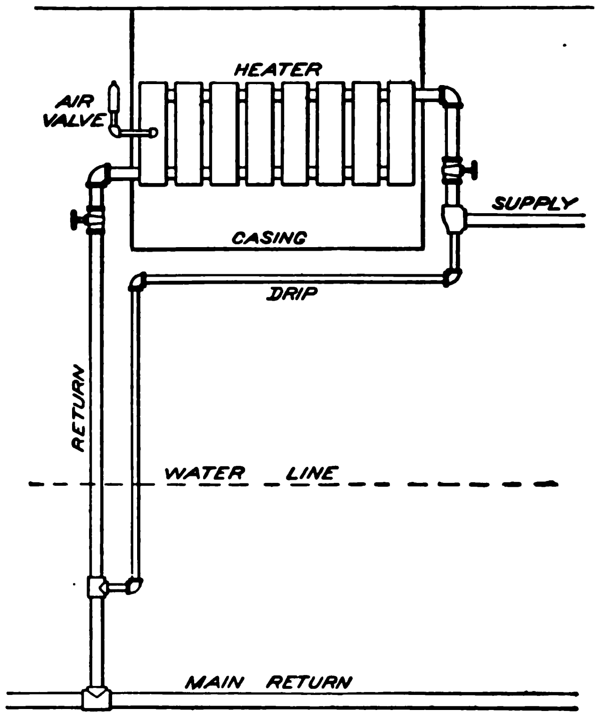


Fig. 75. General Method of Making Pipe and Radiator Connections, in Basement, in Indirect Heating.

As the indirect heaters are placed in the basement, care must be taken that the bottom of the radiator does not come too near the water-line of the boiler, or the condensation will not flow back properly; this distance, under ordinary conditions, should not be less than 2 feet. If much less than this, the pipes should be made extra large, so that there may be little or no drop in pressure between the boiler

TABLE XXV

Indirect Radiating Surface Supplied by Pipes of Various Sizes

Size of Pipe	Square Feet of Indirect Radiation which will be Supplied with		
	¼ Pound Drop in 200 Feet	¼ Pound Drop in 100 Feet	½ Pound Drop in 100 Feet
1 in.	28	40	57
1¼ "	51	72	105
1½ "	67	95	170
2 "	185	262	375
2½ "	335	475	675
3 "	540	775	1, 105
3½ "	812	1, 160	1, 645
4 "	1, 140	1, 625	2, 310
5 "	2, 030	2, 900	4, 110
6 "	3, 260	4, 660	6, 600
7 "	4, 830	6, 900	9, 810
8 "	6, 800	9, 720	13, 860

and the heater. A drop in pressure of 1 pound would raise the water-line at the heater 2.4 feet.

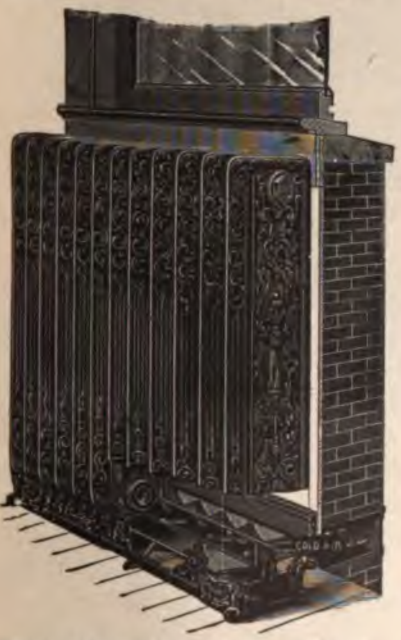


Fig. 76. General Form of Direct-Indirect Radiator.

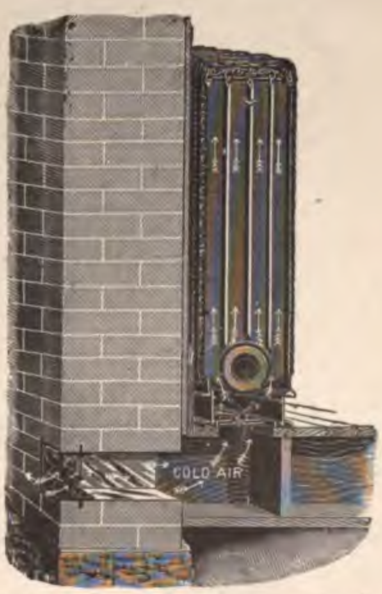


Fig. 77. Section through Radiator Shown in Fig. 76.

Direct-Indirect Radiators. A direct-indirect radiator is similar in form to a direct radiator, and is placed in a room in the same manner. Fig. 76 shows the general form of this type of radiator; and Fig. 77 shows a section through the same. The shape of the sections is such, that when in place, small flues are formed between them. Air is admitted through an opening in the outside wall; and, in passing upward through these flues, becomes heated before entering the room. A switch-damper is placed in the duct at the base of the radiator, so that the air may be taken from the room itself instead of from out of doors, if so desired. This is shown more particularly in Fig. 76.

Fig. 78 shows the wall box provided with louvre slats and netting, through which the air is drawn. A damper door is placed at either end of the radiator base; and, if desired, when the cold-air supply is shut off by means of the register in the air-duct, the radiator can be converted into the ordinary type by opening both damper doors, thus taking the air from the room instead of from the outside. It is customary to increase the size of a direct-indirect radiator 30 per cent above that called for in the case of direct heating.

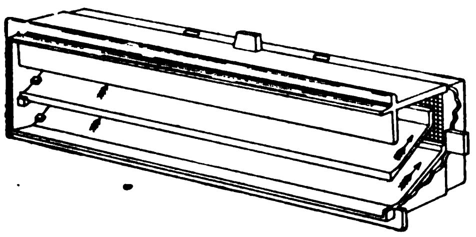


Fig. 78. Wall Box with Louvre Slats and Netting, Direct-Indirect System.

CARE AND MANAGEMENT OF STEAM-HEATING BOILERS

Special directions are usually supplied by the maker for each kind of boiler, or for those which are to be managed in any peculiar way. The following general directions apply to all makes, and may be used regardless of the type of boiler employed:

Before starting the fire, see that the boiler contains sufficient water. The water-line should be at about the center of the gauge-glass.

The smoke-pipe and chimney flue should be clean, and the draft good.

Build the fire in the usual way, using a quality of coal which is best adapted to the heater. In operating the fire, keep the firepot full of coal, and shake down and remove all ashes and cinders as often as the state of the fire requires it.

Hot ashes or cinders must not be allowed to remain in the ashpit under the grate-bars, but must be removed at regular intervals to prevent burning out the grate.

To control the fire, see that the damper regulator is properly attached to the draft doors and the damper; then regulate the draft by weighting the automatic lever as may be required to obtain the necessary steam pressure for warming. Should the water in the boiler escape by means of a broken gauge-glass, or from any other cause, the fire should be dumped, and the boiler allowed to cool before adding cold water.

An empty boiler should never be filled when hot. If the water gets low at any time, but still shows in the gauge-glass, more water should be added by the means provided for this purpose.

The safety-valve should be lifted occasionally to see that it is in working order.

If the boiler is used in connection with a gravity system, it should be cleaned each year by filling with pure water and emptying through the blow-off. If it should become foul or dirty, it can be thoroughly cleansed by adding a few pounds of caustic soda, and allowing it to stand for a day, and then emptying and thoroughly rinsing.

During the summer months, it is recommended that the water be drawn off from the system, and that air-valves and safety-valves be opened to permit the heater to dry out and to remain so. Good results, however, are obtained by filling the heater full of water, driving off the air by boiling slowly, and allowing it to remain in this condition until needed in the fall. The water should then be drawn off and fresh water added.

The heating surface of the boiler should be kept clean and free from ashes and soot by means of a brush made especially for this purpose.

Should any of the rooms fail to heat, examine the steam valves in the radiators. If a two-pipe system, both valves at each radiator must be opened or closed at the same time, as required. See that the air-valves are in working condition.

If the building is to be unoccupied in cold weather, draw all the water out of the system by opening the blow-off pipe at the boiler and all steam valves and air-valves at the radiators.

HOT-WATER HEATERS

Types. Hot-water heaters differ from steam boilers principally in the omission of the reservoir or space for steam above the heating surface. The steam boiler might answer as a heater for hot water; but the large capacity left for the steam would tend to make its operation slow and rather unsatisfactory, although the same type of boiler is sometimes used for both steam and hot water. The passages in a hot-water heater need not extend so directly from bottom to top as in a steam boiler, since the problem of providing for the free liberation of the steam bubbles does not have to be considered. In general, the heat from the furnace should strike the surfaces in such a manner as to increase the natural circulation; this may be accomplished to a certain extent by arranging the heating surface so that a large proportion of the direct heat will be absorbed near the top of the heater. Practically the boilers for low-pressure steam and for hot water differ from each other very little as to the character of the heating surface, so that the methods already given for computing the size of grate surface, horse-power, etc., under the head of "Steam Boilers," can be

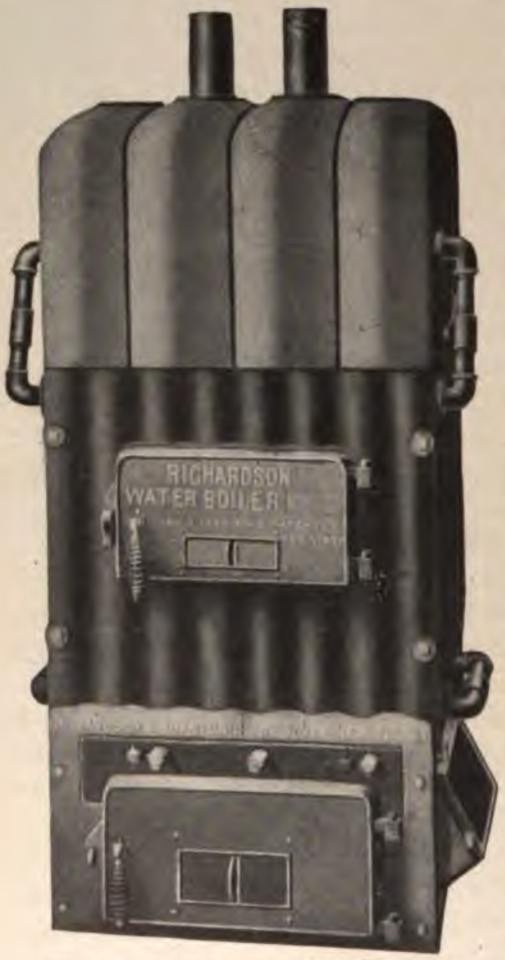


Fig. 79. Richardson Sectional Hot-Water Heater.

used with satisfactory results in the case of hot-water heaters.

It is sometimes stated that, owing to the greater difference in temperature between the furnace gases and the water in a hot-water heater, as compared with steam, the heating surface will be more efficient and a smaller heater can be used. While this is true to a certain extent, different authorities agree that this advantage is so small that no account should be taken of it, and the general proportions of the heater should be calculated in the same manner as for steam. Fig. 79 shows a form of hot-water heater made up of slabs or sections similar to the sectional steam boiler shown in Part I. The size can be increased in a similar manner, by adding more sections. In this case, however, the boiler is increased in width instead of in length. This has an advantage in the larger sizes, as a second fire door can be added, and all parts of the grate can be reached as well in the large sizes as in the small.

Fig. 80 shows a different form of sectional boiler, in which the sections are placed one above another. These boilers are circular in form and well adapted to dwelling-houses and similar work.

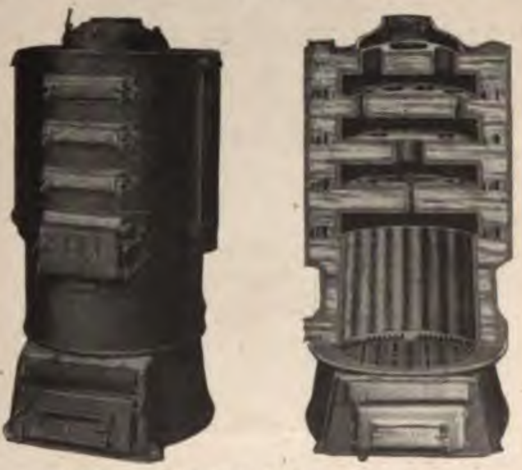


Fig. 80. "Invincible" Boiler, with Sections Superposed.
Courtesy of American Radiator Co.

Fig. 81 shows another type of cast-iron heater which is not made in sections. The space between the outer and inner shells surrounding the furnace is filled with water, and also the cross-pipes directly over the fire and the drum at the top. The supply to the radiators is taken off from the top of the heater, and the return connects at the lowest point.

The ordinary horizontal and vertical tubular boilers, with various modifications, are used to a considerable extent for hot-water heating, and are well adapted to this class of work, especially in the case of large buildings.

Automatic regulators are often used for the purpose of maintaining a constant temperature of the water. They are constructed in different ways—some depend upon the expansion of a metal pipe or rod at different temperatures, and others upon the vaporization and consequent pressure of certain volatile liquids. These means are usually employed to open small valves which admit water-pressure under rubber diaphragms; and these in turn are connected by means of chains with the draft doors of the furnace, and so regulate the draft as required to maintain an even temperature of the water in the heater. Fig. 82 shows one of the first kind. *A* is a metal rod placed in the flow pipe from the heater, and is so connected with the valve *B* that when the water reaches a certain temperature the expansion of the rod opens the valve and admits water from the street pressure through the pipes *C* and *D* into the chamber *E*. The bottom of *E* consists of a rubber diaphragm, which is forced down by the water-pressure and carries with it the lever which operates the dampers as shown, and checks the fire. When the temperature of the water drops, the rod contracts and valve *B* closes, shutting off the pressure from the chamber *E*. A spring is provided to throw the lever back to its original position,

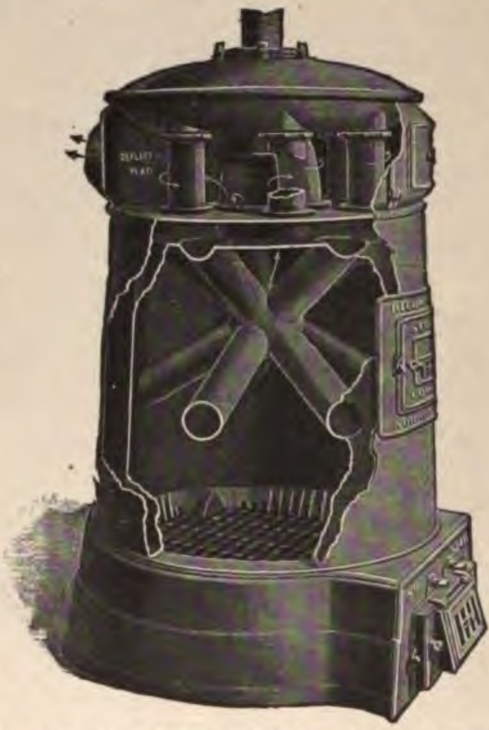


Fig. 81. Cast-Iron Heater Not Made in Sections. Water Fills Cross-Pipes and Space between Outer and Inner Shells.

and the water above the diaphragm is forced out through the pet-cock *G*, which is kept slightly open all the time.

DIRECT HOT-WATER HEATING

A hot-water system is similar in construction and operation to one designed for steam, except that *hot water* flows through the pipes and radiators instead.

The circulation through the pipes is produced solely by the difference in weight of the water in the supply and return, due to the difference in temperature. When water is heated it expands, and thus a given volume becomes lighter and tends to rise, and the cooler water flows in to take its place; if the application of heat is kept up, the circulation thus produced is continuous. The velocity of flow depends upon the difference in temperature between the supply and return, and the height of the radiator above the boiler. The horizontal distance of the radiator from the boiler is also an important factor affecting the velocity of flow.

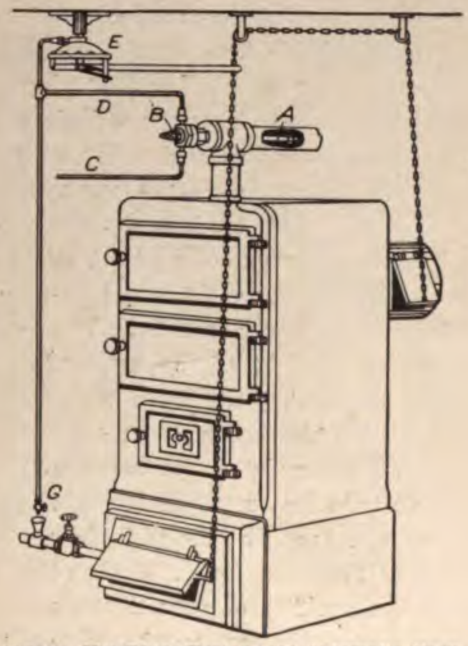


Fig. 82. Hot-Water Heater with Automatic Regulator Operated through Expansion and Contraction of Metal Rod in Flow Pipe.

This action is best shown by means of a diagram, as in Fig. 83. If a glass tube of the form shown in the figure is filled with water and held in a vertical position, no movement of the water will be noticed, because the two columns *A* and *B* are of the same weight, and therefore in equilibrium. Now, if a lamp flame be held near the tube *A*, the small bubbles of steam which are formed will show the water to be in motion, with a current flowing in the direction indicated by the arrows. The reason for this is, that, as the water in *A* is heated, it expands and becomes lighter for a given volume, and is forced upward by the heavier water in *B* falling to the bottom of the tube. The heated water flows from *A* through the connecting tube at the top, into *B*, where it takes the place of the cooler water which is settling to the bottom. If, now, the lamp be replaced by a furnace, and the columns *A* and *B* be connected at the top by inserting a radiator, the illustration will assume the practical form as utilized in hot-water heating (see Fig. 84).

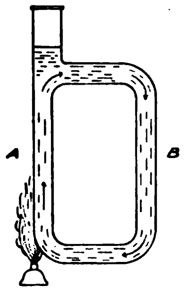


Fig. 83. Illustrating How the Heating of Water Causes Circulation.

The heat given off by the radiator always insures a difference in temperature between the columns of water in the supply and return pipes, so that as long as heat is supplied by the furnace the flow of water will continue. The greater the difference in temperature of the water in the two pipes, the greater the difference in weight, and consequently the faster the flow. The greater the height of the radiator above the heater, the more rapid will be the circulation, because the total difference in weight between the water in the supply and return risers will vary directly with their height. From the above it is evident that the rapidity of flow depends chiefly upon the *temperature* difference between the supply and return, and upon the *height of the radiator* above the heater. Another factor which must be considered in long runs of horizontal pipe is the *frictional resistance.*

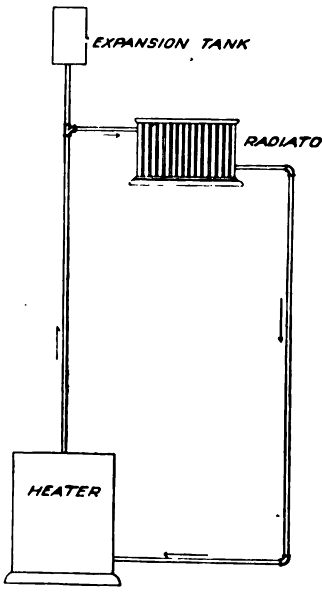


Fig. 84. Illustrating Simple Circulation in a Heating System.

Systems of Circulation. There are two distinct systems of circulation employed—one depending on the difference in temperature of the water in the supply and return pipes, called *gravity circulation*;

and another where a pump is used to force the water through the mains, called *forced circulation*. The former is used for dwellings and other buildings of ordinary size, and the latter for large buildings, and especially where there are long horizontal runs of pipe.

For gravity circulation some form of sectional cast-iron boiler is commonly used, although wrought-iron tubular boilers may be employed if desired. In the case of forced circulation, a heater designed to warm the water by means of live or exhaust steam is often used. A centrifugal or rotary pump is best adapted to this purpose, and may be driven by an electric motor or a steam engine, as most convenient.

Types of Radiating Surface. Cast-iron radiators and circulation coils are used for hot water as well as for steam. Hot-water radiators differ from steam radiators principally in having a horizontal passage at the top as well as at the bottom. This construction is necessary in order to draw off the air which gathers at the top of each loop or section. Otherwise they are the same as steam radiators, and are well adapted for the circulation of steam, and in some respects are superior to the ordinary pattern of steam radiator.

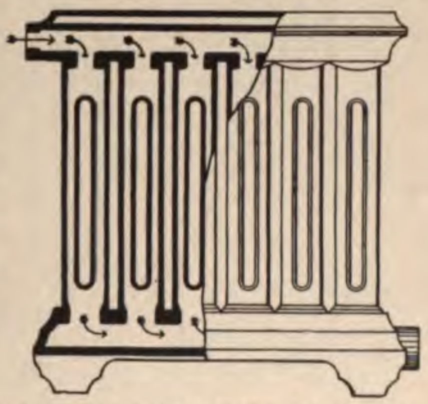


Fig. 85. Showing Construction of Radiator for Hot Water or Steam. Note Horizontal Passage along Top.

The form shown in Fig. 85 is made with an opening at the top for the entrance of water, and at the bottom for its discharge, thus insuring a supply of hot water at the top and of colder water at the bottom.

Some hot-water radiators are made with a cross-partition so arranged that all water entering passes at once to the top, from which it may take any passage toward the outlet. Fig. 86 is the more common form of radiator, and is made with continuous passages at top and bottom, the hot water being supplied at one side and drawn off at the other. The action of gravity is depended upon for making the hot and lighter water pass to the top, and the colder water sink to the bottom and flow off through the return. Hot-water radiators are usually tapped and plugged so that the pipe connections can be made either at the top or at the bottom. This is shown in Fig. 87.

Wall radiators are adapted to hot-water as well as steam heating.

Efficiency of Radiators. The efficiency of a hot-water radiator depends entirely upon the temperature at which the water is circulated. The best practical results are obtained with the water leaving the boiler at a maximum temperature of about 180 degrees in zero weather and returning at about 160 degrees; this gives an average temperature of 170 degrees in the radiators. Variations may be made, however, to suit the existing conditions of outside temperature. We have seen that an average cast-iron radiator gives off about 1.7 B.T.U. per hour per square foot of surface per degree difference in temperature between the radiator and the surrounding air, when working under ordinary conditions; and this holds true whether it is filled with steam or water.

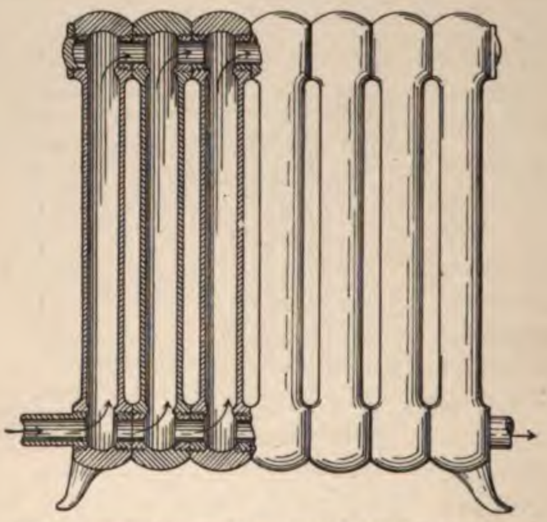


Fig. 86. Common Form of Hot-Water Radiator. Circulation Produced Wholly through Action of Gravity, Hot Water Rising to Top.

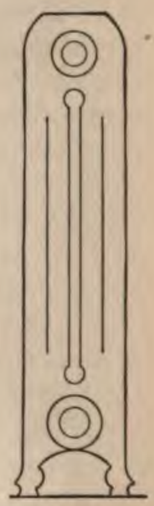


Fig. 87. End Elevation of Radiator Showing Taps at Top and Bottom for Pipe Connections.

If we assume an average temperature of 170 degrees for the water, then the difference in temperature between the radiator and the air will be 170 — 70 = 100 degrees; and this multiplied by 1.7 =

170, which may be taken as the efficiency of a hot-water radiator under the above average conditions.

This calls for a water radiator about 1.5 times as large as a steam radiator to heat a given room under the same conditions. This is common practice although some engineers multiply by the factor 1.6, which allows for a lower temperature of the water. Water leaving the boiler at 170 degrees should return at about 150; the drop in temperature should not ordinarily exceed 20 degrees.

Systems of Piping. A system of hot-water heating should produce a perfect circulation of water from the heater to the radiating surface, and thence back to the heater through the returns. The system of piping usually employed for hot-water heating is shown in Fig. 88. In this arrangement the main and branches have an inclination upward from the heater; the returns are parallel to the mains, and have an inclination downward toward the heater, connecting with it at the lowest point. The flow pipes or risers are taken from the tops of the mains, and may supply one or more radiators as required. The return risers or drops are connected with the return mains in a similar manner. In this system great care must be taken to produce a nearly equal resistance to flow in all of the branches, so that each radiator may receive its full supply of water. It will always

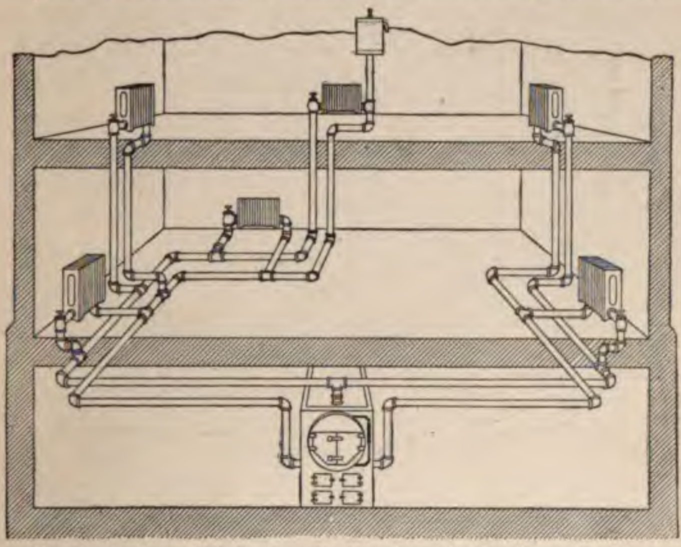


Fig. 88. System of Piping Usually Employed for Hot-Water Heating.

be found that the principal current of heated water will take the path of least resistance, and that a small obstruction or irregularity in the piping is sufficient to interfere greatly with the amount of heat received in the different parts of the same system.

Some engineers prefer to carry a single supply main around the building, of sufficient size to supply all the radiators, bringing back a single return of the same size. Practice has shown that in general it is not well to use pipes over 8 or 10 inches in diameter; if larger pipes are required, it is better to run two or more branches.

The boiler, if possible, should be centrally located, and branches carried to different parts of the building. This insures a more even circulation than if all the radiators are supplied from a single long main, in which case the circulation is liable to be sluggish at the farther end.

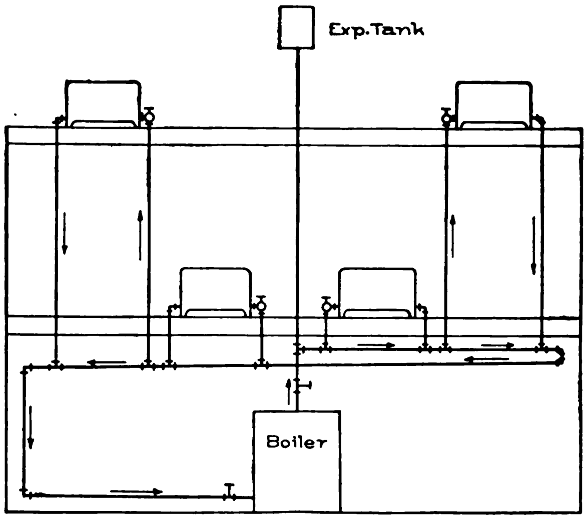
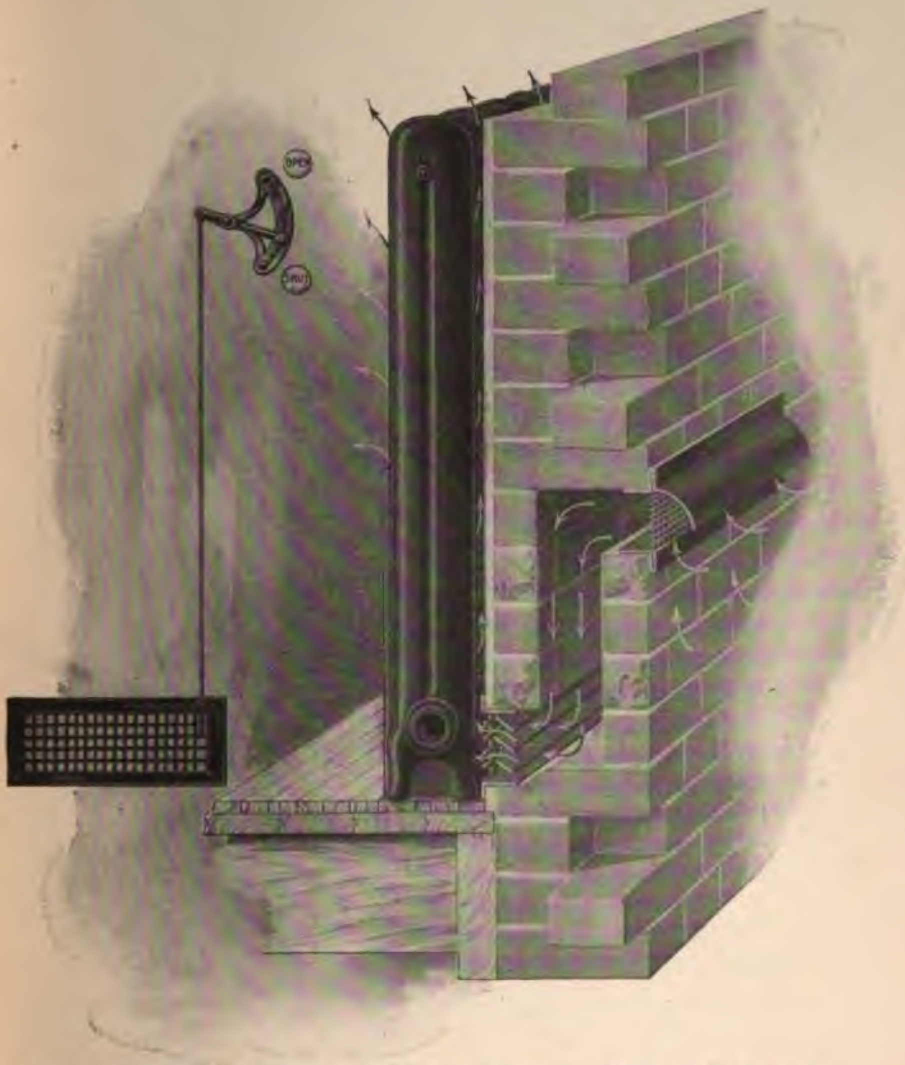


Fig. 89. System of Hot-Water Piping Especially Adapted to Apartment Buildings where Each Flat Has a Separate Heater.

The arrangement shown in Fig. 89 is similar to the circuit system for steam, except that the radiators have two connections instead of one. This method is especially adapted to apartment houses, where each flat has its separate heater, as it eliminates a separate return main, and thus reduces, by practically one-half, the amount of piping in the basement. The supply risers are taken from the top of the main; while the returns should connect into the side a short distance beyond, and in a direction *away* from the boiler. When this system is used, it is necessary to enlarge the radiators slightly as the distance from the boiler increases.

In flats of eight or ten rooms, the size of the last radiator may be increased from 10 to 15 per cent, and the intermediate ones propor-



DIRECT-INDIRECT SYSTEM OF WARMING, SHOWING ADJUSTABLE DAMPER.
American Radiator Company.

tionally, at the same time keeping the main of a large and uniform size for the entire circuit.

Overhead Distribution. This system of piping is shown in Fig. 90. A single riser is carried directly to the expansion tank, from which branches are taken to supply the various drops to which the radiators are connected. An important advantage in connection with this system is that the air rises at once to the expansion tank, and escapes through the vent, so that air-valves are not required on the radiators.

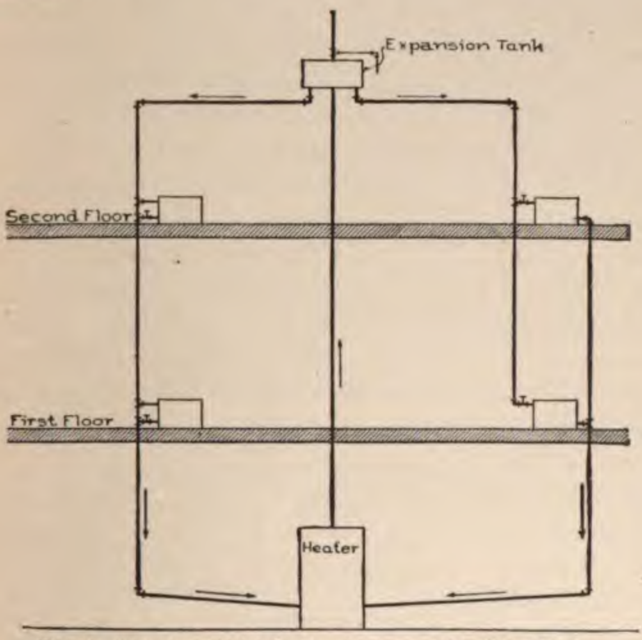


Fig. 90. "Overhead" Distribution System of Hot-Water Piping.

At the same time, it has the disadvantage that the water in the tank is under less pressure than in the heater; hence it will boil at a lower temperature. No trouble will be experienced from this, however, unless the temperature of the water is raised above 212 degrees.

Expansion Tank. Every system for hot-water heating should be connected with an expansion tank placed at a point somewhat above the highest radiator. The tank must in every case be connected to a line of piping which cannot by any possible means be shut off from the boiler. When water is heated, it expands a certain amount, depending upon the temperature to which it is raised; and a tank or reservoir should always be provided to care for this increase in volume.

Expansion tanks are usually made of heavy galvanized iron of one of the forms shown in Figs. 91 and 92, the latter form being used where the headroom is limited. The connection from the heating system enters the bottom of the tank, and an open vent pipe is taken from the top. An overflow connected with a sink or drain-pipe should be provided. Connections should be made with the water supply both at the boiler and at the expansion tank, the former to be used when first filling the system, as by this means all air is driven from the bottom upward and is discharged through the vent at the expansion tank. Water that is added afterward may be supplied directly to the expansion tank, where the water-line can be noted in the gauge-glass. A ball-cock is sometimes arranged to keep the water-line in the tank at a constant level.

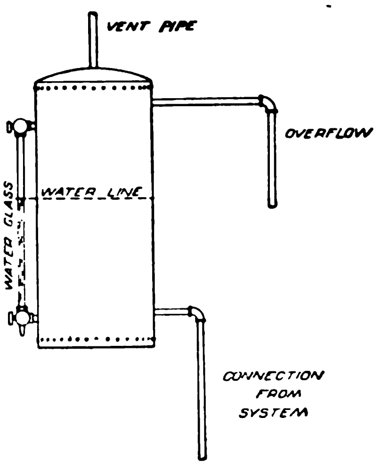


Fig. 91. A Common Form of Galvanized-Iron Expansion Tank.

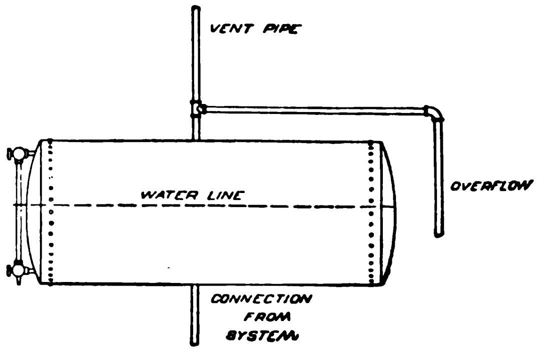


Fig. 92. Form of Expansion Tank Used where Headroom is Limited.

An *altitude gauge* is often placed in the basement with the colored hand or pointer set to indicate the normal water-line in the expansion tank. When the movable hand falls below the fixed one, more water may be added, as required, through the supply pipe at the boiler. When the tank is placed in an attic or roof space where there is danger of freezing, the expansion pipe may be connected into the side of the tank, 6 or 8 inches from the bottom, and a circulation pipe taken from the lower part and connected with the return from an upper-floor radiator. This produces a slow circulation through the tank, and keeps the water warm.

The size of the expansion tank depends upon the volume of water contained in the system, and on the temperature to which it is heated. The following rule for computing the capacity of the tank may be used with satisfactory results:

Square feet of radiation, *divided by* 40, equals required capacity of tank in gallons.

Air-Venting. One very important point to be kept in mind in the design of a hot-water system, is the removal of air from the pipes and radiators. When the water in the boiler is heated, the air it contains forms into small bubbles which rise to the highest points of the system.

In the arrangement shown in Fig. 88, the main and branches grade upward from the boiler, so that the air finds its way into the radiators, from which it may be drawn off by means of the air-valves.

A better plan is that shown in Fig. 89. In this case the expansion pipe is taken directly off the top of the main over the boiler, so that the larger part of the air rises directly to the expansion tank and escapes through the vent pipe. The same action takes place in the overhead system shown in Fig. 90, where the top of the main riser is connected with the tank. Every high point in the system and every radiator, except in the downward system with top supply connection, should be provided with an air-valve.

Pipe Connections. There are various methods of connecting the radiators with the mains and risers. Fig. 93 shows a radiator connected with the horizontal flow and return mains, which are located below the floor. The manner of connecting with a vertical riser and return drop is shown in Fig. 94. As the water tends to flow to the highest point, the radiators on the lower floors should be favored by making the connection at the top of the riser and taking the pipe for the upper floors from the side as shown. Fig. 95 illustrates the manner of connecting with a radiator on an upper floor where the supply is connected at the top of the radiator.

The connections shown in Figs. 96 and 97 are used with the overhead system shown in Fig. 90.

Where the connection is of the form shown at the left in Fig. 90, the cooler water from the radiators is discharged into the supply pipe again, so that the water furnished to the radiators on the lower floors is at a lower temperature, and the amount of heating surface must be correspondingly increased to make up for this loss, as already described for the circuit system.

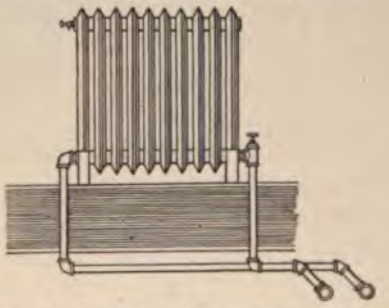


Fig. 93. Radiator Connected with Horizontal Flow and Return Mains Located below Floor.

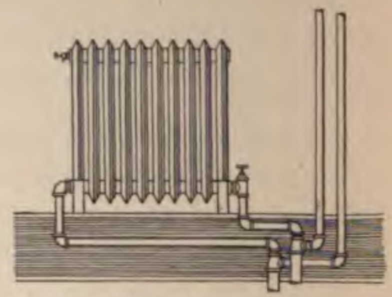


Fig. 94. Radiator Connected to Vertical Riser and Return Drop.

For example, if in the case of Fig. 90 we assume the water to leave at 180 degrees and return at 160, we shall have a drop in temperature of 10 degrees on each floor; that is, the water will enter the radiator on the second floor at 180 degrees and leave it at 170, and will enter the radiator on the first floor at 170 and leave it at 160.

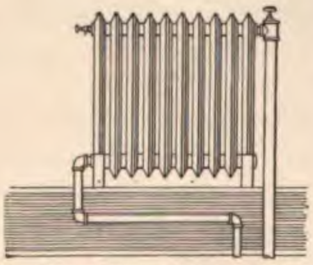


Fig. 95. Upper-Floor Radiator with Supply Connected at Top.

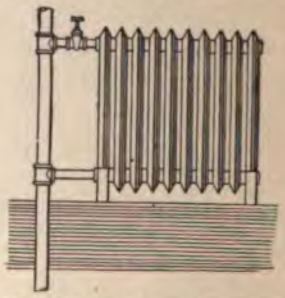


Fig 96. Radiator Connections, Overhead Distribution System.

The average temperatures will be 175 and 165, respectively. The efficiency in the first case will be 175 — 70 = 105; and 105 × 1.5 = 157. In the second case, 165 — 70 = 95; and 95 × 1.5 = 142; so that the radiator on the first floor will have to be larger than that on the second floor in the ratio of 157 to 142, in order to do the same work.

This is approximately an increase of 10 per cent for each story downward to offset the cooling effect; but in practice the supply drops are made of such size that only a part of the water is by-passed through the radiators. For this reason an increase of 5 per cent for each story downward is probably sufficient in ordinary cases.

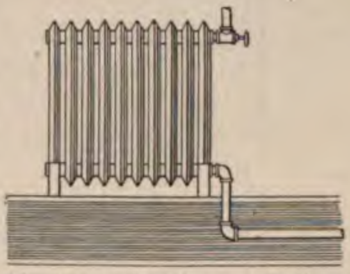


Fig. 97. Another Form of Radiator Connection, Overhead Distribution System.

Where the radiators discharge into a separate return as in the case of Fig. 88, or those at the right in Fig. 90, we may assume the temperature of the water to be the same on all floors, and give the radiators an equal efficiency.

In a dwelling-house of two stories, no difference would be made in the sizes of radiators on the two floors; but in the case of a tall office building, corrections would necessarily be made as above described.

Where circulation coils are used, they should be of a form which will tend to produce a flow of water through them. Figs. 98, 99, and 100 show different ways of making up and connecting these coils. In Figs. 98 and 100, supply pipes may be either drops or risers; and in the former case the return in Fig. 100 may be carried back, if desired, into the supply drop, as shown by the dotted lines.

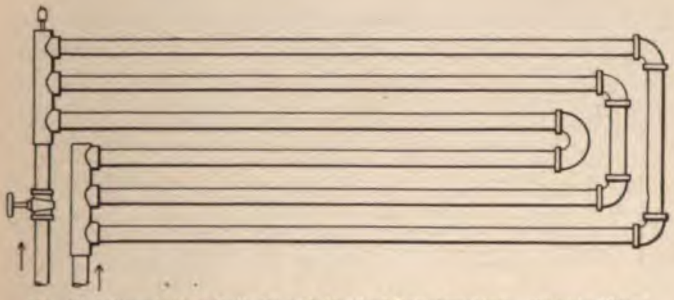


Fig. 98. Circulation Coil, One Method of Construction. Supply Pipes may be Either Drops or Risers.

Combination Systems. Sometimes the boiler and piping are arranged for either steam or hot water, since the demand for a higher or lower temperature of the radiators might change.

The object of this arrangement is to secure the advantages of a hot-water system for moderate temperatures, and of steam heating for extremely cold weather.

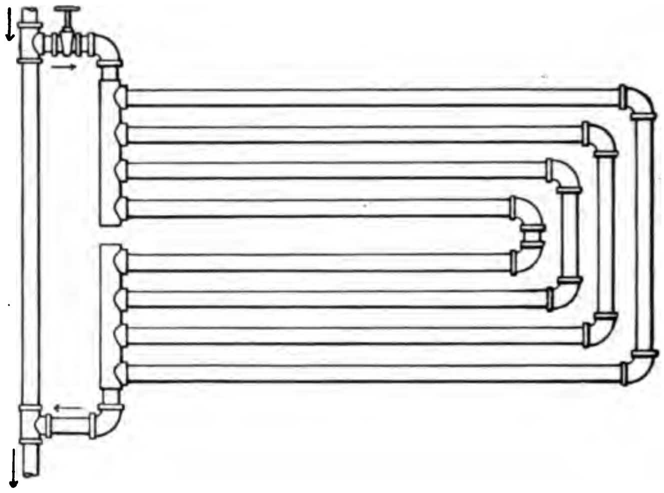


Fig. 99. Another Method of Building Up a Circulation Coil.

As less radiating surface is required for steam heating, there is an advantage due to the reduction in first cost. This is of considerable importance, as a heating system must be designed of such dimensions as to be capable of warming a building in the coldest weather; and this involves the expenditure of a considerable amount for radiating surfaces, which are needed only at rare intervals. A combination system of hot-water and steam heating requires, *first*, a heater or boiler

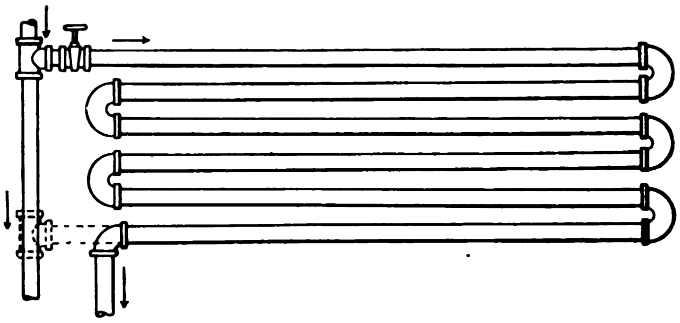


Fig. 100. Circulation Coil with Either Drop or Riser Supply. In former case, return may be carried into Supply Drop as shown by Dotted Lines.

which will answer for either purpose; *second*, a system of piping which will permit the circulation of either steam or hot water; and *third*, the use of radiators which are adapted to both kinds of heating. These requirements will be met by using a steam boiler provided with all the fittings required for steam heating, but so arranged that the damper regulator may be closed by means of valves when the system is to be used for hot-water heating. The addition of an expansion tank is required, which must be so arranged that it can be shut off when the system is used for steam heating. The system of piping shown in Fig. 88 is best adapted for a combination system, although an overhead distribution as shown in Fig. 90 may be used by shutting off the vent and overflow pipes, and placing air-valves on the radiators.

While this system has many advantages in the way of cost over the complete hot-water system, the labor of changing from steam to hot water will in some cases be troublesome; and should the connections to the expansion tank not be opened, serious results would follow.

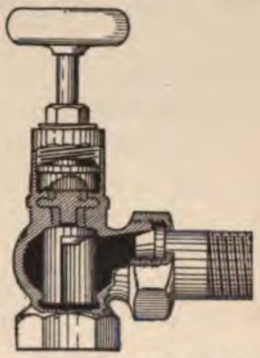


Fig. 101. Radiator Valve for Hot-Water Work.

Valves and Fittings. Gate-valves should always be used in connection with hot-water piping, although angle-valves may be used at the radiators. There are several patterns of radiator valves made especially for hot-water work; their chief advantage lies in a device for quick closing, usually a quarter-turn or half-turn being sufficient to open or close the valve. Two different designs are shown in Figs. 101 and 102.

It is customary to place a valve in only one connection, as that is sufficient to stop the flow of water through the radiator; a fitting known as a *union elbow* is often employed in place of the second valve. (See Fig. 103.)

Air-Valves. The ordinary pet-cock air-valve is the most reliable for hot-water radiators, although there are several forms of automatic valves which are claimed to give satisfaction. One of these is shown in Fig. 104. This is similar in construction to a steam trap. As air collects in the chamber, and the water-line is lowered, the float drops, and in so doing opens a small valve at the top of the chamber, which allows the air to escape. As the water flows in to take its place, the float is forced upward and the valve is closed.

All radiators which are supplied by risers from below, should be provided with air-valves placed in the top of the last section at the return end. If they are supplied by drops from an overhead system, the air will be discharged at the expansion tank, and air-valves will not be necessary at the radiators.

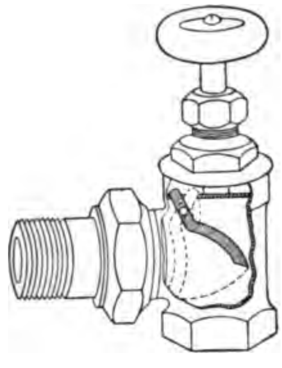


Fig. 102. Another Type of Hot-Water Radiator Valve.

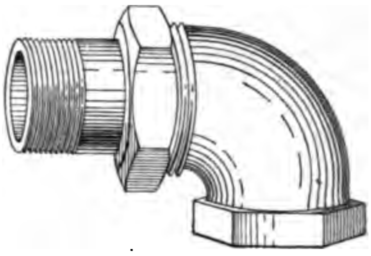


Fig. 103. Union Elbow.

Fittings. All fittings, such as elbows, tees, etc., should be of the *long-turn* pattern. If the common form is used, they should be a size larger than the pipe, bushed down to the proper size. The long-turn fittings, however, are preferable, and give a much better appearance. Connections between the radiators and risers may be made with the ordinary short-pattern fittings, as those of the other form are not well adapted to the close connections necessary for this work.

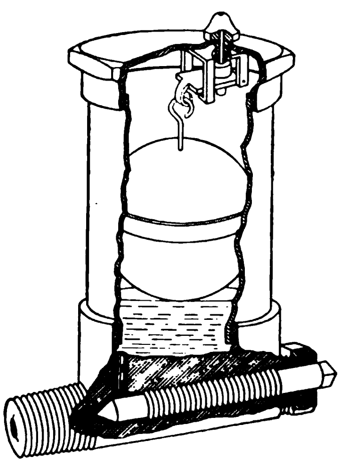


Fig. 104. Automatic Air-Valve for Hot-Water Radiator. Operated by a Float.

Pipe Sizes. The size of pipe required to supply any given radiator depends upon four conditions; *first*, the size of the radiator; *second*, its elevation above the boiler; *third*, the length of pipe required to connect it with the boiler; and *fourth*, the difference in temperature between the supply and the return.

As it would be a long and rather complicated process to work out the required size of each pipe for a heating system, Tables XXVI and XXVII have been prepared, covering the usual conditions to be met with in practice.

TABLE XXVI

Direct Radiating Surface Supplied by Mains of Different Sizes and Lengths of Run

SIZE OF PIPE	SQUARE FEET OF RADIATING SURFACE								
	100 ft. Run	200 ft. Run	300 ft. Run	400 ft. Run	500 ft. Run	600 ft. Run	700 ft. Run	800 ft. Run	1,000 ft. Run
1 in.	30								
1¼ "	60	50							
1½ "	100	75	50						
2 "	200	150	125	100	75				
2½ "	350	250	200	175	150	125			
3 "	550	400	300	275	250	225	200	175	150
3½ "	850	600	450	400	350	325	300	250	225
4 "	1,200	850	700	600	525	475	450	400	350
5 "		1,400	1,150	1,000	700	850	775	725	650
6 "				1,600	1,400	1,300	1,200	1,150	1,000
7 "							1,706	1,600	1,500

These quantities have been calculated on a basis of 10 feet difference in elevation between the center of the heater and the radiators, and a difference in temperature of 17 degrees between the supply and the return.

TABLE XXVII

Radiating Surface on Different Floors Supplied by Pipes of Different Sizes

SIZE OF RISER	SQUARE FEET OF RADIATING SURFACE					
	1st Story	2d Story	3d Story	4th Story	5th Story	6th Story
1 in.	30	55	65	75	85	95
1¼ "	60	90	110	125	140	160
1½ "	100	140	165	185	210	240
2 "	200	275	375	425	500	
2½ "	350	475				
3 "	550					
3½ "	850					

Table XXVI gives the number of square feet of direct radiation which different sizes of mains and branches will supply for varying lengths of run.

Table XXVI may be used for all horizontal mains. For vertical risers or drops, Table XXVII may be used. This has been computed for the same difference in temperature as in the case of Table XXVI (17 degrees), and gives the square feet of surface which different sizes of pipe will supply on the different floors of a building, assuming the height of the stories to be 10 feet. Where a single riser is carried to the top of a building to supply the radiators on the floors below, by drop pipes, we must first get what is called the ***average elevation of the system*** before taking its size from the table. This may be illustrated by means of a diagram (see Fig. 105).

In *A* we have a riser carried to the third story, and from there a drop brought down to supply a radiator on the first floor. The elevation available for producing a flow in the riser is only 10 feet, the same as though it extended only to the radiator. The water in the two pipes above the radiator is practically at the same temperature, and therefore in equilibrium, and has no effect on the flow of the water in the riser. (Actually there would be some radiation from the pipes, and the return, above the radiator, would be slightly cooler, but for purposes of illustration this may be neglected). If the radiator was on the second floor the elevation of the system would be 20 feet (see *B*); and on the third floor, 30 feet; and so on. The distance which the pipe is carried above the first radiator which it supplies has but little effect in producing a flow, especially if covered, as it should be in practice. Having seen that the flow in the main riser depends upon the elevation of the radiators, it is easy to see that the way in which it is distributed on the different floors must be considered. For example, in *B*, Fig. 105, there will be a more rapid flow through the riser with the radiators as shown, than there would be if they were reversed and the largest one were placed upon the first floor.

We get the average elevation of the system by multiplying the square feet of radiation on each floor by the elevation above the heater, then adding these products together and dividing the same by the total radiation in the whole system. In the case shown in *B*, the average elevation of the system would be

$$\frac{(100 \times 30) + (50 \times 20) + (25 \times 10)}{100 + 50 + 25} = 24 \text{ feet};$$

and we must proportion the main riser the same as though the whole radiation were on the second floor. Looking in Table XXVII, we find, for the second story, that a 1½-inch pipe will supply 140 square feet; and a 2-inch pipe, 275 feet. Probably a 1½-inch pipe would be sufficient.

Although the height of stories varies in different buildings, 10 feet will be found sufficiently accurate for ordinary practice.

INDIRECT HOT-WATER HEATING

This is used under the same conditions as indirect steam, and the heaters used are similar to those already described. Special attention is given to the form of the sections, in order that there may be an even distribution of water through all parts of them. As the stacks are placed in the basement of a building, and only a short distance above the boiler, extra large pipes must be used to secure a proper circulation, for the *head* producing flow is small. The stack

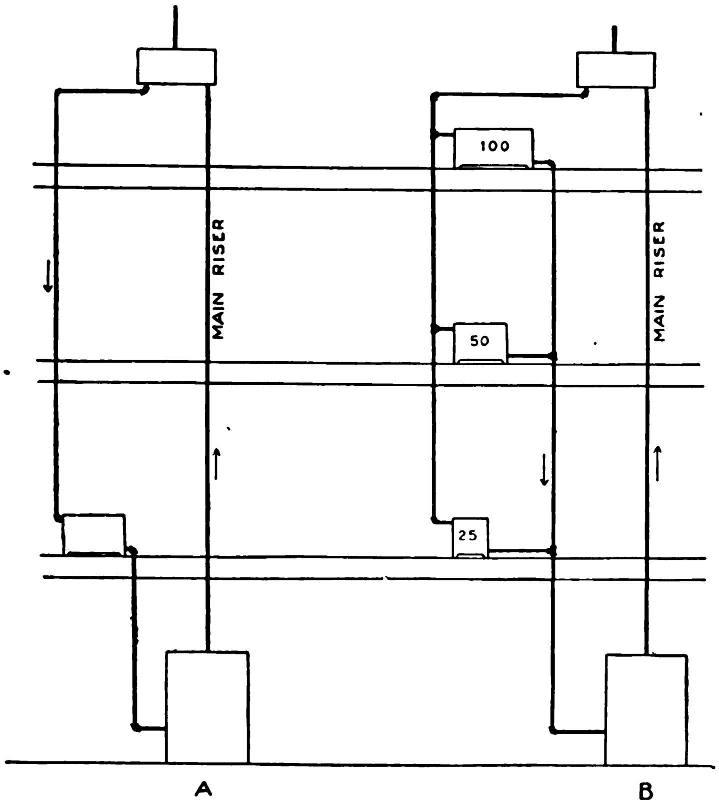


Fig. 105. Diagram to Illustrate Finding of Average Elevation of Heating System.

casings, cold-air and warm-air pipes, and registers are the same as in steam heating.

Types of Radiators. The radiators for indirect hot-water heating are of the same general form as those used for steam. Those shown in Figs. 52, 53, 56, 106, and 107 are common patterns. The *drum pin*, Fig. 106, is an excellent form, as the method of making the connections insures a uniform distribution of water through the stack.

Fig. 107 shows a radiator of good form for water circulation, and also of good depth, which is a necessary point in the design of hot-water radiators. They should be not less than 12 or 15 inches deep for good results. Box coils of the form given for steam may also be used, provided the connections for supply and return are made of good size.

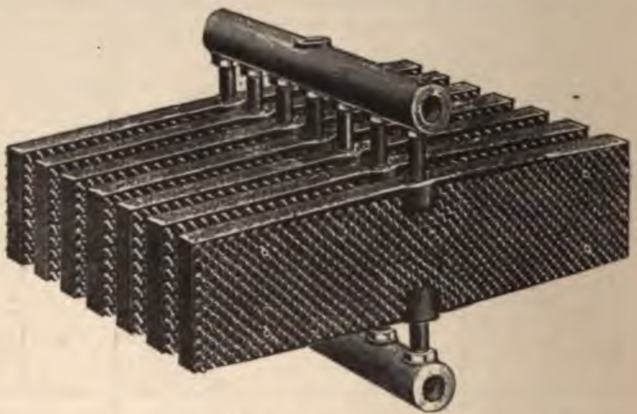


Fig. 106. "Drum Pin" Indirect Hot-Water Radiator.

Size of Stacks. As indirect hot-water heaters are used principally in the warming of dwelling-houses, and in combination with direct radiation, the easiest method is to compute the surfaces required for direct radiation, and multiply these results by 1.5 for pin radiators of good depth. For other forms the factor should vary from 1.5 to 2, depending upon the depth and proportion of free area for air-flow between the sections.

If it is desired to calculate the required surface directly by the thermal unit method, we may allow an efficiency of from 360 to 400 for good types in zero weather.

In schoolhouse and hospital work, where larger volumes of air are warmed to lower temperatures, an efficiency as high as 500 B. T. U. may be allowed for radiators of good form.

Flues and Casings. For cleanliness, as well as for obtaining the best results, indirect stacks should be hung at one side of the register or flue receiving the warm air, and the cold-air duct should enter beneath the heater at the other side. A space of at least 10 inches, and preferably 12, should be allowed for the warm air above the stack. The top of the casing should pitch upward toward the warm-air outlet at least an inch in its length. A space of from 8 to 10 inches should be allowed for cold air below the stack.

As the amount of air warmed per square foot of heating surface is less than in the case of steam, we may make the flues somewhat smaller as compared with the size of heater. The following proportions may be used under usual conditions for dwelling-houses: 1½ square inches per square foot of radiation for the first floor, 1¼ square inches for the second floor, and 1¼ square inches for the cold-air duct.

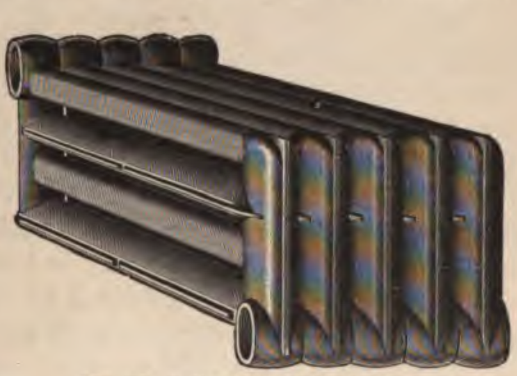


Fig. 107. Indirect Hot-Water Radiator.

Pipe Connections. In indirect hot-water work, it is not desirable to supply more than 80 to 100 square feet of radiation from a single connection. When the requirements call for larger stacks, they should be divided into two or more groups according to size.

It is customary to carry up the main from the boiler to a point near the basement ceiling, where it is air-vented through a small pipe leading to the expansion tank. The various branches should grade downward and connect with the tops of the stacks. In this way, all air, both from the boiler and from the stacks, will find its way to the highest point in the main, and be carried off automatically.

As an additional precaution, a pet-cock air-valve should be placed in the last section of each stack, and brought out through the casing by means of a short pipe.

TABLE XXVIII

Radiating Surface Supplied by Pipes of Various Sizes—Indirect Hot-Water System

Diameter of Pipe	Square Feet of Radiating Surface			
	100 Ft. Run	200 Ft. Run	300 Ft. Run	400 Ft. Run
1 in.	15			
1¼ "	30	25		
1½ "	50	40	25	
2 "	100	75	60	50
2½ "	175	125	100	90
3 "	275	200	150	140
3½ "	425	300	225	200
4 "	600	425	350	300
5 "		700	575	500
6 "				800
7 "				1,200

Some engineers make a practice of carrying the main to the ceiling of the first story, and then dropping to the basement before branching to the stacks, the idea being to accelerate the flow of water through the main, which is liable to be sluggish on account of the small difference in elevation between the boiler and stacks. If the return leg of the loop is left uncovered, there will be a slight drop in temperature, tending to produce this result; but in any case it will be exceedingly small. With supply and return mains of suitable size and properly graded, there should be no difficulty in securing a good circulation in basements of average height.

Pipe Sizes. As the difference in elevation between the stacks and the heater is necessarily small, the pipes should be of ample size to offset the slow velocity of flow through them. The sizes mentioned in Table XXVIII, for runs up to 400 feet, will be found to supply ample radiating surface for ordinary conditions. Some engineers make a practice of using somewhat smaller pipes, but the larger sizes will in general be found more satisfactory.

CARE AND MANAGEMENT OF HOT-WATER HEATERS

The directions given for the care of steam-heating boilers apply in a general way to hot-water heaters, as to the methods of caring for the fires and for cleaning and filling the heater. Only the special points of difference need be considered. Before building the fire, all the pipes and radiators must be full of water, and the expansion tank should be partially filled as indicated by the gauge-glass. Should the water in any of the radiators fail to circulate, see that the valves are wide open and that the radiator is free from air. Water must always be added at the expansion tank when for any reason it is drawn from the system.

The required temperature of the water will depend upon the outside conditions, and only enough fire should be carried to keep the rooms comfortably warm. Thermometers should be placed in the flow and return pipes near the heater, as a guide. Special forms are made for this purpose, in which the bulb is immersed in a bath of oil or mercury (see Fig. 108).

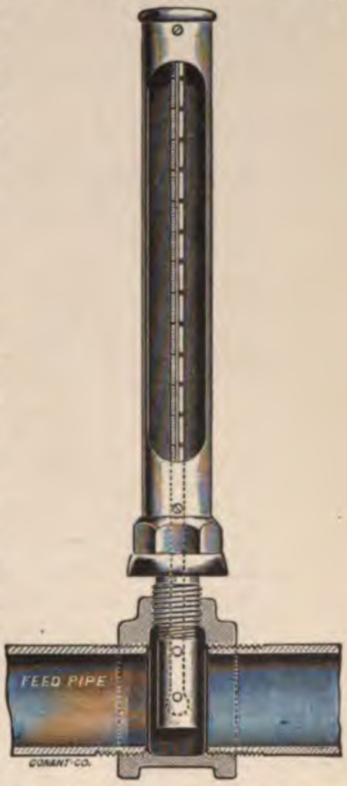


Fig. 108. Thermometer Attached to Feed-Pipe near Heater, to Determine Temperature of Water.

FORCED HOT-WATER CIRCULATION

While the gravity system of hot-water heating is well adapted to buildings of small and medium size, there is a limit to which it can be carried economically. This is due to the slow movement of the water, which calls for pipes of excessive size. To overcome this difficulty, pumps are used to force the water through the mains at a comparatively high velocity.

The water may be heated in a boiler in the same manner as for gravity circulation, or exhaust steam may be utilized in a feed-water heater of large size. Sometimes part of the heat is derived from an economizer placed in the smoke passage from the boilers.

Systems of Piping. The mains for forced circulation are usually run in one of two ways. In the *two-pipe system*, shown in Fig. 109, the supply and return are carried side by side, the former reducing in size, and the latter increasing as the branches are taken off.

The flow through the risers is produced by the difference in pressure in the supply and return mains; and as this is greatest nearest the pump, it is necessary to place throttle-valves in the risers to prevent short-circuiting and to secure an even distribution through all parts of the system.

Fig. 110 shows the *single-pipe* or *circuit system.* This is similar to the one already described for gravity circulation, except that it can be used on a much larger scale.

A single main is carried entirely around the building in this case, the ends being connected with the suction and discharge of the pump as shown.

As the pressure or head in the main drops constantly throughout the circuit, from the discharge of the pump back to the suction, it is evident that if a supply riser be taken off at any point, and the return be connected into the main a short distance along the line, there will be a sufficient difference in pressure between the two points to produce a circulation through the two risers and the connecting radiators. A distance of 8 or 10 feet between the connections is usually ample to produce the necessary circulation, and even less if the supply is taken from the top of the main and the return connected into the side.

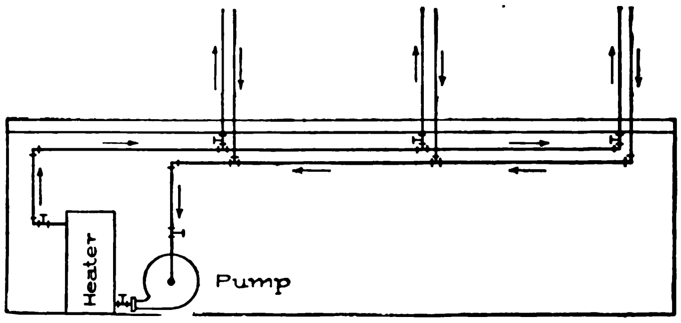


Fig. 109. "Two-Pipe" System for Forced Hot-Water Circulation.

Sizes of Mains and Branches. As the velocity of flow is independent of the temperature and elevation when a pump is used, it is necessary to consider only the volume of water to be moved and the length of run.

The volume is found by the equation

$$Q = \frac{R\,E}{500\,T},$$

in which

Q = Gallons of water required per minute;
R = Square feet of radiating surface to be supplied;
E = Efficiency of radiating surface in B. T. U. per sq. foot per hour;
T = Drop in temperature of the water in passing through the heating system.

In systems of this kind, where the circulation is comparatively rapid, it is customary to assume a drop in temperature of 30° to 40°, between the supply and return.

Having determined the gallons of water to be moved, the required size of main can be found by assuming the velocity of flow, which for pipes from 5 to 8 inches in diameter may be taken at 400 to 500 feet per minute. A velocity as high as 600 feet is sometimes allowed for pipes of large size, while the velocity in those of smaller diameter should be proportionally reduced to 250 or 300 feet for a 3-inch pipe. The next step is to find the pressure or head necessary to force the water through the main at the given velocity. This in general should not exceed 50 or 60 feet, and much better pump efficiencies will be obtained with heads not exceeding 35 or 40 feet.

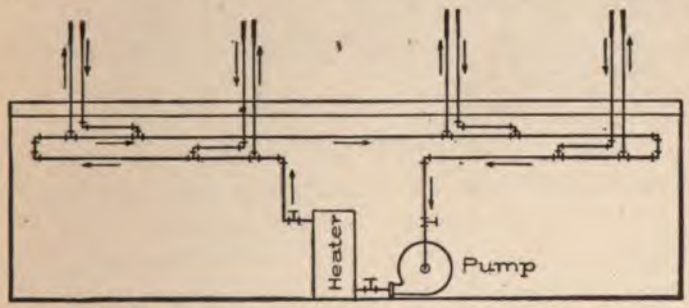


Fig. 110. "Single-Pipe" or "Circuit" System for Forced Hot-Water Circulation.

As the water in a heating system is in a state of equilibrium, the only power necessary to produce a circulation is that required to overcome the friction in the pipes and radiators; and, as the area of the passageways through the latter is usually large in comparison with the former, it is customary to consider only the head necessary to force the water through the mains, taking into consideration the additional friction produced by valves and fittings.

Each long-turn elbow may be taken as adding about 4 feet to the length of pipe; a short-turn fitting, about 9 feet; 6-inch and 4-inch swing check-valves, 50 feet and 25 feet, respectively; and 6-inch and 4-inch globe check-valves, 200 feet and 130 feet, respectively.

Table XXIX is prepared especially for determining the size of mains for different conditions, and is used as follows:

Example. Suppose that a heating system requires the circulation of 480 gallons of water per minute through a circuit main 600 feet in length. The pipe contains 12 long-turn elbows and 1 swing check-valve. What diameter of main should be used ?

Assuming a velocity of 480 feet per minute as a trial velocity, we follow along the line corresponding to that velocity, and find that a 5-inch pipe will deliver the required volume of water under a head of 4.9 feet for each 100 feet length of run.

The actual length of the main, including the equivalent of the fittings as additional length, is

$$600 + (12 \times 9) + 50 = 758 \text{ feet};$$

hence the total head required is $4.9 \times 7.58 = 37$ feet. As both the assumed velocity and the necessary head come within practicable limits, this is the size of pipe which would probably be used. If it were desired to reduce the power for running the pump, the size of main could be increased. That is, Table XXIX shows that a 6-inch pipe would deliver the same volume of water with a friction head of only about 2 feet per 100 feet in length, or a total head of $2 \times 7.58 = 15$ feet.

The risers in the circuit system are usually made the same size as for gravity work. With double mains, as shown in Fig. 109, they may be somewhat smaller, a reduction of one size for diameters over 1¼ inches being common

The branches connecting the risers with the mains may be proportioned from the combined areas of the risers. When the branches are of considerable size, the diameter may be computed from the available head and volume of water to be moved.

Pumps. Centrifugal pumps are usually employed in connection with forced hot-water circulation, in preference to pumps of the piston or plunger type. They are simple in construction, having no valves, produce a continuous flow of water, and, for the low heads

TABLE XXIX

Capacity in Gallons per Minute Discharged at Velocities of 300 to 540 Feet per Minute—Also Friction Head in Feet, per 100 Feet Length of Pipe

	DIAMETER OF PIPE											
	3-INCH		4-INCH		5-INCH		6-INCH		7-INCH		8-INCH	
Velocity	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction
300	110	3.41	195	2.56	306	2.05	440	1.70	600	1.46	783	1.28
480	176	8.16	314	6.12	490	4.9	705	4.08	959	3.49	1,253	3.06
540	198	10.1	352	7.64	550	6.11	794	5.09	1,079	4.36	1,410	3.82

against which they are operated, have a good efficiency. A pump of this type, with a direct-connected engine, is shown in Fig. 111.

Under ordinary conditions the efficiency of a centrifugal pump falls off considerably for heads above 30 or 35 feet; but special high-speed pumps are constructed which work with a good efficiency against 500 feet or more.

Under favorable conditions an efficiency of 60 to 70 per cent is often obtained; but for hot-water circulation it is more common to assume an efficiency of about 50 per cent for the average case.

The horse-power required for driving a pump is given by the following formula:

$$\text{H. P.} = \frac{H \times V \times 8.3}{33{,}000 \times E},$$

in which

H = Friction head in feet;
V = Gallons of water delivered per minute;
E = Efficiency of pump.

Centrifugal pumps are made in many sizes and with varying proportions, to meet the different requirements of capacity and head.

Heaters. If the water is heated in a boiler, any good form may be used, the same as for gravity work. In case tubular boilers are used, the entire shell may be filled with tubes, as no steam space is required.

In order to prevent the water from passing in a direct line from the inlet to the outlet, a series of baffle-plates should be used to bring it in contact with all parts of the heating surface.

When steam is used for heating the water, it is customary to employ a closed feed-water heater with the steam on the inside of the tubes and the water on the outside.

Any good form of heater can be used for this purpose by providing it with steam connections of sufficient size. In the ordinary form of heater, the feed-water flows through the tubes, and the connections are therefore small, making it necessary to substitute special nozzles of large size when used in the manner here described.

When computing the required amount of heating surface in the tubes of a heater, it is customary to assume an efficiency of about 200 B. T. U. per square foot of surface per hour, per degree difference in temperature between the water and steam.

It is usual to circulate the water at a somewhat higher temperature in systems of this kind, and a maximum initial temperature of 200 degrees, with a drop of 40 degrees in the heating system, may be used in computing the size of heater. If exhaust steam is used at atmospheric pressure, there will be a difference of 212 − 180 = 32 degrees, between the *average* temperature of the water and the steam, giving an efficiency of 200 × 32 = 6,400 B. T. U. per square foot of heating surface.

From this it is evident that 6,400 ÷ 170 = 38 square feet of direct radiating surface, or 6,400 ÷ 400 = 16 square feet of indirect, may be supplied from each square foot of tube surface in the heater.

Example. A building having 6,000 square feet of direct, and 2,000 square feet of indirect radiation, is to be warmed by hot water under forced circulation. Steam at atmospheric pressure is to be used for heating the water. How many square feet of heating surface should the heater contain?

6,000 ÷ 38 = 158; and 2,000 ÷ 16 = 125; therefore, 158 + 125 = 283 square feet, the area of heating surface called for.

When the exhaust steam is not sufficient for the requirements, an auxiliary live steam heater is used in connection with it.

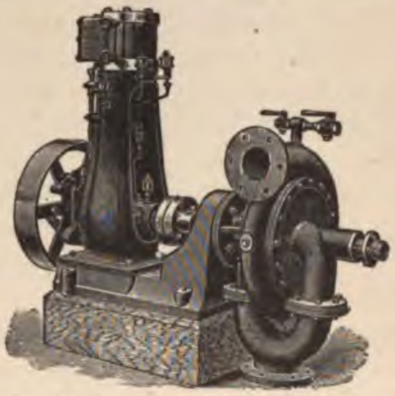


Fig. 111. Centrifugal Pump Direct-Connected to Engine, for Forced Hot-Water Circulation.

EXAMPLES FOR PRACTICE

1. A building contains 10,000 square feet of direct radiation and 4,000 square feet of indirect radiation. How many gallons of water must be circulated through the mains per minute, allowing a drop in temperature of 40 degrees? Ans. 165 gal.

2. In the above example, what size of main should be used, assuming the circuit to be 300 feet in length and to contain ten long-turn elbows? The friction head is not to exceed 10 ft., and the velocity of flow not to exceed 300 feet per minute. Ans. 4-inch.

3. What horse-power will be required to drive a centrifugal pump delivering 400 gallons per minute against a friction head of 40 feet, assuming an efficiency of 50 per cent for the pump?
Ans. 8 H. P.

4. A building contains 10,000 square feet of direct radiation and 5,000 square feet of indirect radiation. Steam at atmospheric pressure is to be used. The initial temperature of the water is to be 200°; and the final, 160°. How many square feet of heating surface should the heater contain? Ans. 575 sq. ft.

5. How many square feet would be required in the above heater (Example 4) if the initial temperature of the water were 180° and the final temperature 150°? Ans. 399 sq. ft.

EXHAUST-STEAM HEATING

Steam, after being used in an engine, contains the greater part of its heat; and if not condensed or used for other purposes, it can usually be employed for heating without affecting to any great extent the power of the engine. In general, we may say that it is a matter of economy to use the exhaust for heating, although various factors must be considered in each case to determine to what extent this is true. The more important considerations bearing upon the matter are: the relative quantities of steam required for power and for heating; the length of the heating season; the type of engine used; the pressure carried; and, finally, whether the plant under consideration is entirely new, or whether, on the other hand, it involves the adapting of an old heating system to a new plant.

The first use to be made of the exhaust steam is the heating of the feed-water, as this effects a constant saving both summer and winter, and can be done without materially increasing the back-pressure on the engine. Under ordinary conditions, about one-sixth of the steam supplied to the engine can be used in this way, or more nearly one-fifth of the exhaust *discharged* from the engine.

We may assume in average practice that about 80 per cent of the steam supplied to an engine is discharged in the form of steam at a lower pressure, the remaining 20 per cent being partly converted into work and partly lost through cylinder condensation. Taking this into account, there remains, after deducting the steam used for feed-water heating, $.8 \times \frac{4}{5} = .64$ of the entire quantity of steam supplied to the engine, available for heating purposes.

When the quantity of steam required for heating is small compared with the total amount supplied to the engine, or where the heating season is short, it is often more economical to run the engine condensing and use the live steam for heating. This can be determined in any particular case by computing the saving in fuel by the use of a condenser, taking into account the interest and depreciation on the first cost of the condensing apparatus, and the cost of water, if it must be purchased, and comparing it with the cost of heating with live steam.

Usually, however, in the case of office buildings and institutions, and commonly in the case of shops and factories, especially in northerly latitudes, it is advantageous to use the exhaust for heating, even if a condenser is installed for summer use only. The principal objection raised to the use of exhaust steam has been the higher back-pressure required on the engines, resulting in a loss of power nearly proportional to the ratio of the back-pressure to the mean effective pressure. There are two ways of offsetting this loss—one, by raising the initial or boiler pressure; and the other, by increasing the cut-off of the engine. Engines are usually designed to work most economically at a given cut-off, so that in most cases it is undesirable to change it to any extent. Raising the boiler pressure, on the other hand, is not so objectionable if the increase amounts to only a few pounds.

Under ordinary conditions in the case of a simple engine, a rise of 3 pounds in the back-pressure calls for an increase of about 5 pounds in the boiler pressure, to maintain the same power at the engine.

The indicator card shows a back-pressure of about 2 pounds when an engine is exhausting into the atmosphere, so that an increase of 3 pounds would bring the pressure up to a total of 5 pounds which should be more than sufficient to circulate the steam through any well-designed heating system.

If it is desired to reduce rather than increase the back-pressure, one of the so-called *vacuum systems*, described later, can be used.

The systems of steam heating which have been described are those in which the water of condensation flows back into the boiler by gravity. Where exhaust steam is used, the pressure is much below that of the boiler, and it must be returned either by a pump or by a return trap. The exhaust steam is often insufficient to supply the entire heating system, and must be supplemented by live steam taken directly from the boiler. This must first pass through a reducing valve in order to reduce the pressure to correspond with that carried in the heating system.

An engine does not deliver steam continuously, but at regular intervals, at the end of each stroke; and the amount is likely to vary with the work done, since the governor is adjusted to admit steam in such a quantity as is required to maintain a uniform speed. If the work is light, very little steam will be admitted to the engine; and for this reason the supply available for heating may vary somewhat, depending upon the use made of the power delivered by the engine. In mills the amount of exhaust steam is practically constant; in office buildings where power is used for lighting, the variation is greater, especially if power is also required for the running of elevators.

The general requirements for a successful system of exhaust steam heating include a system of piping of such proportions that only a slight increase in back-pressure will be thrown upon the engine; a connection which shall automatically supply live steam at a reduced pressure as needed; provision for removing the oil from the exhaust steam; a relief or back-pressure valve arranged to prevent any sudden increase in back pressure on the engine; and a return system of some kind for returning the water of condensation to the boiler against a higher pressure. These requirements may be met in various ways, depending upon actual conditions found in different cases.

To prevent sudden changes in the back-pressure, due to irregular supply of steam, the exhaust pipe from the engine is often carried to a closed tank having a capacity from 30 to 40 times that of the engine cylinder. This tank may be provided with baffle-plates or other arrangements and may serve as a separator for removing the oil from the steam as it passes through.

Any system of piping may be used; but great care should be taken that as little resistance as possible is introduced at bends and fittings; and the mains and branches should be of ample size. Usually the best results are obtained from the system in which the main steam pipe is carried directly to the top of the building, the distributing pipes being run from that point, and the radiating surfaces supplied by a down-flowing current of steam.

Before taking up the matter of piping in detail a few of the more important pieces of apparatus will be described in a brief way.

Reducing Valves. The action of pressure-reducing valves has been taken up quite fully in "Boiler Accessories," and need not be repeated here. When the reduction in pressure is large, as in the case of a combined power and heating plant, the valve may be one or two sizes smaller than the low-pressure main into which it discharges. For example, a 5-inch valve will supply an 8-inch main, a 4-inch a 6-inch main, a 3-inch a 5-inch main, a 2½-inch a 4-inch main, etc.

For the smaller sizes, the difference should not be more than one size. All reducing valves should be provided with a valved by-pass for cutting out the valve in case of repairs. This connection is usually made as shown in plan by Fig. 112.

Grease Extractor. When exhaust steam is used for heating purposes, it must first be passed through some form of separator for removing the oil; and as an additional precaution it is well to pass the water of condensation through a separating tank before returning it to the boilers.

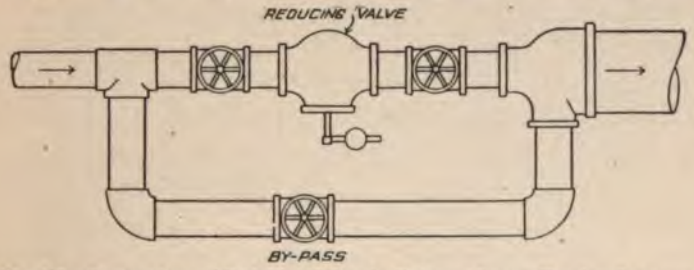


Fig. 112. Connections of Reducing Valve in Exhaust-Steam Heating System.

Such an arrangement is shown in Fig. 113. As the oil collects on the surface of the water in the tank, it can be made to overflow into the sewer by closing the valve in the connection with the receiving tank, for a short time.

As much of the oil as possible should be removed before the steam enters the pipes and radiators, else a coating will be formed on their inner surfaces, which will reduce their heating efficiency. The separation of the oil is usually effected by introducing a series of baffling plates in the path of the steam; the particles of oil striking these are stopped, and thus separated from the steam. The oil drops into a receiver provided for this purpose and is discharged through a trap to the sewer.

In the separator, or extractor, shown in Fig. 114, the separation is accomplished by a series of plates placed in a vertical position in the body of the separator, through which the steam must pass. These plates consist of upright hollow columns, with openings at regular intervals for the admission of water and oil, which drain downward to the receiver below. The steam takes a zigzag course, and all of it comes in contact with the intercepting plates, which insures a thorough separation of the oil and other solid matter from the steam. Another form, shown in Fig. 115, gives excellent results, and has the advantage of providing an equalizing chamber for overcoming, to some extent, the unequal pressure due to the varying load on the engine. It consists of a tank or receiver about 4 feet in diameter, with heavy boiler-iron heads slightly crowned to give stiffness.

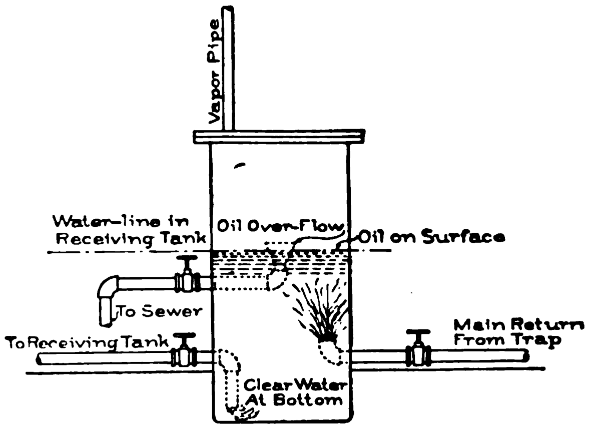


Fig. 113. Separator for Removing Oil from Exhaust Steam and Water Condensation.

Through the center is a layer of excelsior (wooden shavings of long fibre) about 12 inches in thickness, supported on an iron grating, with a similar grating laid over the top to hold it in place. The steam enters the space below the excelsior and passes upward, as shown by the arrows. The oil is caught by the excelsior, which can be renewed from time to time as it becomes saturated. The oil and water which fall to the bottom of the receiver are carried off through a trap. Live steam may be admitted through a reducing valve, for supplementing the exhaust when necessary.

Back-Pressure Valve. This is a form of relief valve which is placed in the outboard exhaust pipe to prevent the pressure in the heating system from rising above a given point. Its office is the reverse of the reducing valve, which supplies more steam when the pressure becomes too low. The form shown in Fig. 116 is designed for a vertical pipe. The valve proper consists of two discs of unequal area, the combined area of which equals that of the pipe. The force tending to open the valve is that due to the steam pressure acting on an area equal to the difference in area between the two discs; it is clear from the cut that the pressure acting on the larger disc tends to open the valve while the pressure on the smaller acts in the opposite direction. The valve-stem is connected by a link and crank arm with a spindle upon which is a lever and weight outside. As the valve opens, the weight is raised, so that, by placing it in different positions on the lever arm, the valve will open at any desired pressure.

Fig. 117 shows a different type, in which a spring is used instead of a weight. This valve has a single disc moving in a vertical direction. The valve stem is in the form of a piston or dash-pot which prevents a too sudden movement and makes it more quiet in its action. The disc is held on its seat against the steam pressure by a lever attached to the spring as shown. When the pressure of the steam on the underside becomes greater than the tension of the spring, the valve lifts and allows the steam to escape. The tension of the spring can be varied by means of the adjusting screw at its upper end.

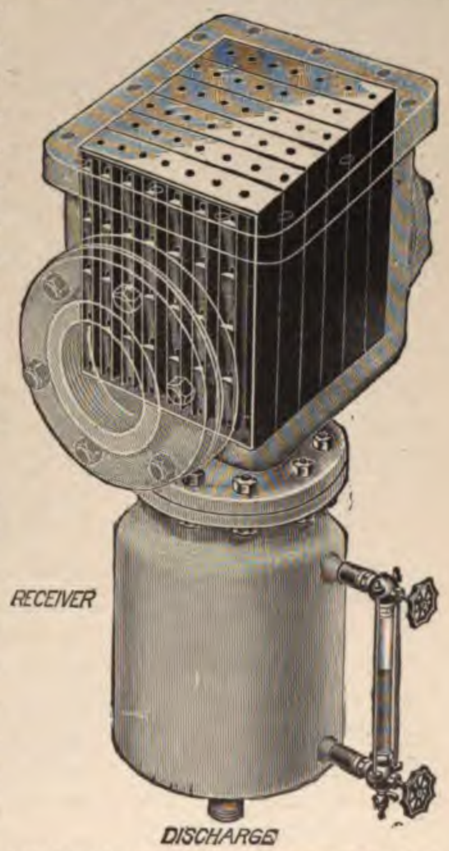


Fig. 114. Oil Separator Consisting of Vertical Plates with Openings Giving Steam a Zigzag Course.

A back-pressure valve is simply a low-pressure safety-valve designed with a specially large opening for the passage of steam through it. These valves are made for horizontal as well as for vertical pipes.

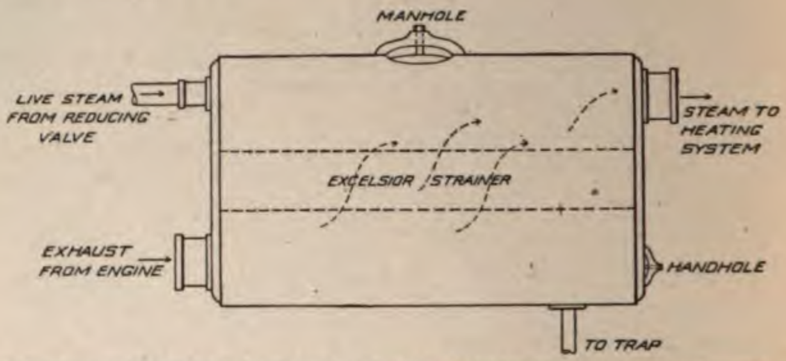


Fig. 115. Oil Separator Consisting of a Tank in which Steam is Filtered by Passing Upward through a Layer of Excelsior.

Exhaust Head. This is a form of separator placed at the top of an outboard exhaust pipe to prevent the water carried up in the steam from falling upon the roofs of buildings or in the street below. Fig. 118 is known as a centrifugal exhaust head. The steam, on entering at the bottom, is given a whirling or rotary motion by the spiral deflectors; and the water is thrown outward by centrifugal force against the sides of the chamber, from which it flows into the shallow trough at the base, and is carried away through the drip-pipe, which is brought down and connected with a drain-pipe inside the building. The passage of the steam outboard is shown by the arrows. Other forms are used in which the water is separated from the steam by deflectors which change the direction of the currents.

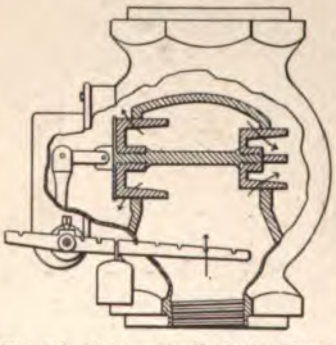


Fig. 116. Automatically Acting Back-Pressure Valve Attached to Vertical Pipe. For Preventing Rise of Pressure in System above any Desired Point.

Automatic Return-Pumps. In exhaust heating plants, the condensation is returned to the boilers by means of some form of return-pump. A combined pump and receiver of the form illustrated in Fig. 119 is generally used. This consists of a cast-iron or wrought-iron tank mounted on a base in connection with a boiler feed-pump. Inside the tank is a ball-float connected by means of levers with a valve in the steam pipe which is connected with the pump. When the water-line in the tank rises above a certain level, the float is raised and opens the steam valve, which starts the pump. When the water is lowered to its normal level, the valve closes and the pump stops. By this arrangement, a constant water-line is maintained in the receiver, and the pump runs only as needed to care for the condensation as it returns from the heating system. If dry returns are used, they may be brought together and connected with the top of the receiver. If it is desired to seal the horizontal runs, as is usually the case, the receiver may be raised to a height sufficient to give the required elevation and the returns connected near the bottom below the water-line.

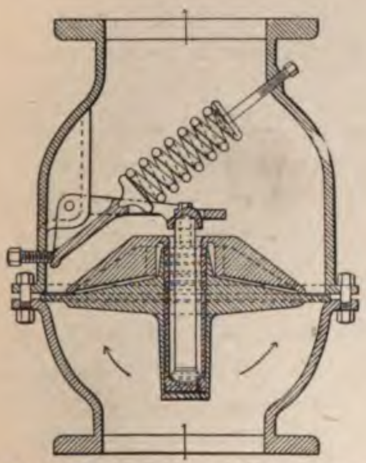


Fig. 117. Back-Pressure Valve Automatically Operated by a Spring.

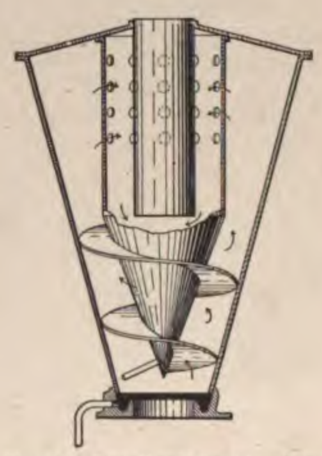


Fig. 118. Centrifugal Exhaust Head.

A *balance-pipe*, so called, should connect the heating main with the top of the tank, for equalizing the pressure; otherwise the steam above the water would condense, and the vacuum thus formed would draw all the water into the tank, leaving the returns practically empty and thus destroying the condition sought. Sometimes an independent regulator or pump governor is used in place of a receiver. One type is shown in Fig. 120. The return main is connected at the upper opening, and the pump suction at the lower. A float inside the chamber operates the steam valve shown at the top, and the pump works automatically as in the case just described.

If it is desired to raise the water-line, the regulator may be elevated to the desired height and connections made as shown in Fig. 121.

Return Traps. The principle of the return trap has been described in "Boiler Accessories," but its practical form and application will be taken up here. The type shown in Fig. 122 has all its working parts outside the trap. It consists of a cast-iron bowl pivoted at *G* and *H*. There is an opening through *G* connecting with the inside of the bowl. The pipe *K* connects through *C* with an interior pipe opening near the top (see Fig. 123). The pipe *D* connects with a receiver, into which all the returns are brought. *A* is a check-valve allowing water to pass through in the direction shown by the arrow. *E* is a pipe connecting with the boiler below the water-line. *B* is a

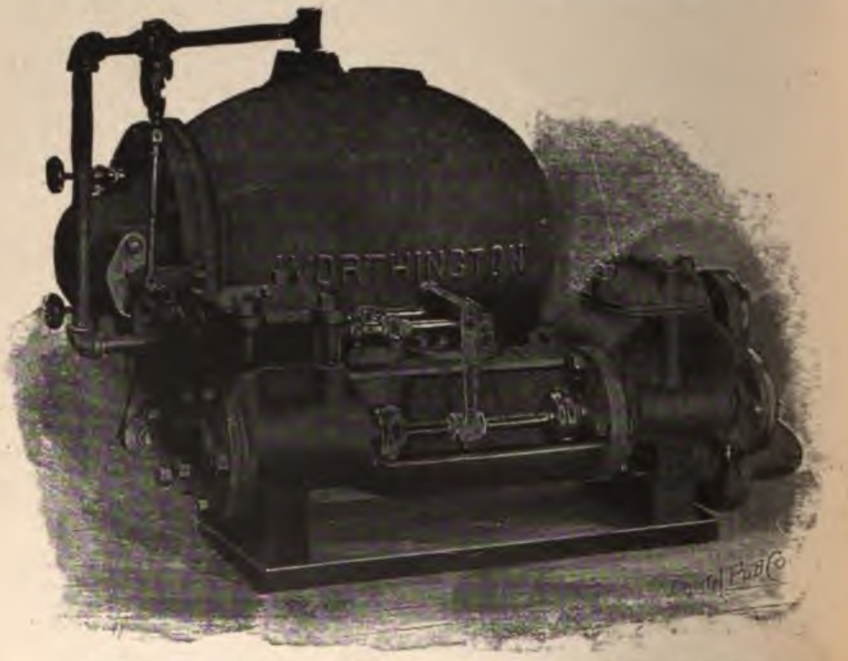


Fig. 119. Combined Receiver and Automatic Pump for Returning Water of Condensation to Boiler.

check opening toward the boiler, and *K*, a pipe connected with the steam main or drum.

The action of the trap is as follows: As the bowl fills with water from the receiver, it overbalances the weighted lever and drops to the bottom of the ring. This opens the valve *C*, and admits steam at boiler pressure to the top of the trap. Being at a higher level the water flows by gravity into the boiler, through the pipe *E*. Water and steam are kept from passing out through *D* by the check *A*.

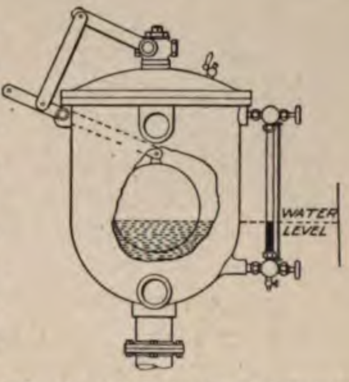


Fig. 120. Automatic Float-Operated Pump Governor Used instead of a Receiver.

When the trap has emptied itself, the weight of the ball raises it to the original position, which movement closes the valve *C* and opens the small vent *F*. The pressure in the bowl being relieved, water flows in from the receiver through *D*, until the trap is filled, when the process is repeated. In order to work satisfactorily, the trap should be placed at least 3 feet above the water-level in the boiler, and the

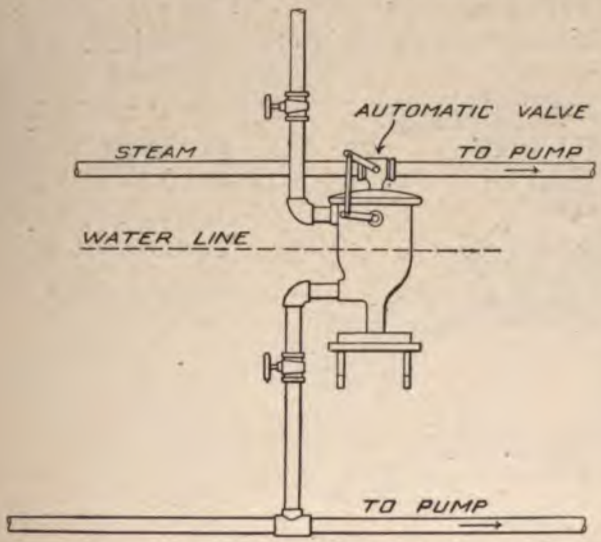


Fig. 121. Pump Regulator Placed at Sufficient Height to Raise Water-Line to Point Desired.

pressure in the returns must always be sufficient to raise the water from the receiver to the trap against atmospheric pressure, which is theoretically about 1 pound for every 2 feet in height. In practice there will be more or less friction to overcome, and suitable adjustments must be made for each particular case.

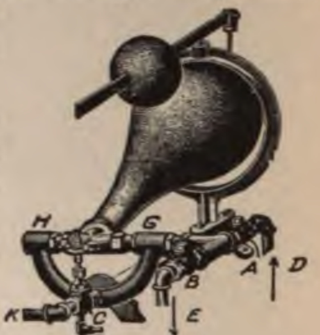


Fig. 122. Return Trap with Working Parts External.

Fig. 124 shows another form of trap acting upon the same principle, except that in this case the steam valve is operated by a bucket or float inside the trap. The pipe connections are practically the same as with the trap just described.

Return traps are more commonly used in smaller plants where it is desired to avoid the expense and care of a pump.

Damper-Regulators. Every heating and every power plant should be provided with automatic means for closing the dampers when the steam pressure reaches a certain point, and for opening them again when the pressure drops. There are various regulators designed for this purpose, a simple form of which is shown in Fig. 125.

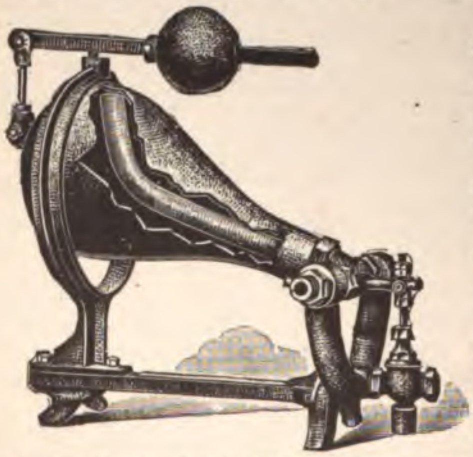
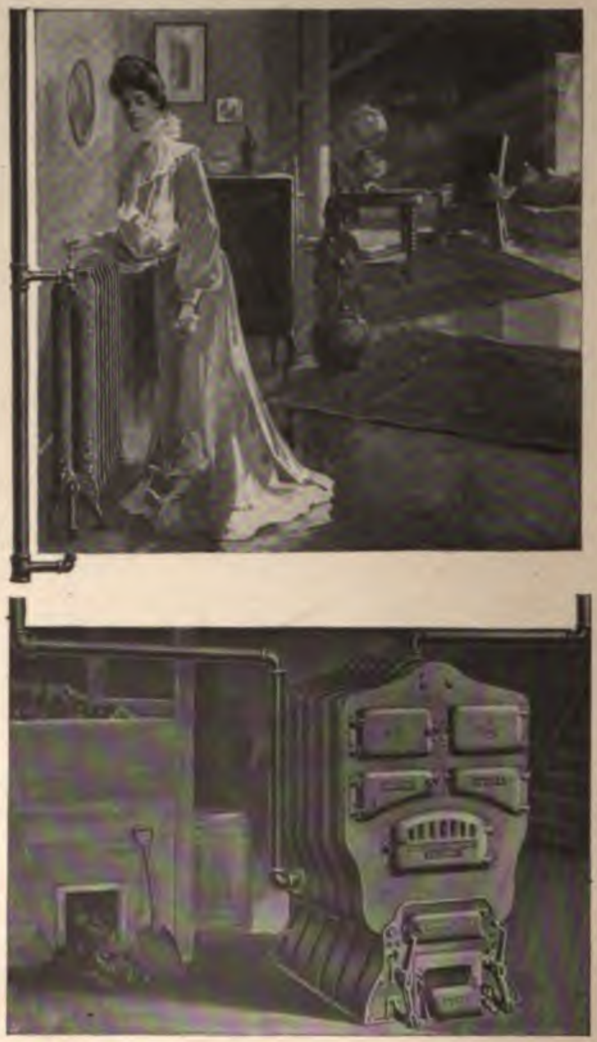


Fig. 123. Showing Interior Detail of Return Trap of Fig. 122.

Steam at boiler pressure is admitted beneath a diaphragm which is balanced by a weighted lever. When the pressure rises to a certain point, it raises the lever slightly and opens a valve which admits water under pressure above a diaphragm located near the smoke-pipe. This action forces down a lever connected by chains with the damper, and closes it. When the steam pressure drops, the water-valve is closed, and the different parts of the apparatus take their original positions.

Another form similar in principle is shown in Fig. 126. In this



TYPICAL HEATING INSTALLATION SHOWING SECTIONAL BOILER AND RADIATOR.
American Radiator Company.

case a piston is operated by the water-pressure, instead of a diaphragm. In both types the pressures at which the damper shall open and close are regulated by suitable adjustments of the weights upon the levers.

Pipe Connections. The method of making the pipe connections in any particular case will depend upon the general arrangement of the apparatus and the various conditions. Fig. 127 illustrates the general principles to be followed, and by suitable changes may be used as a guide in the design of new systems.

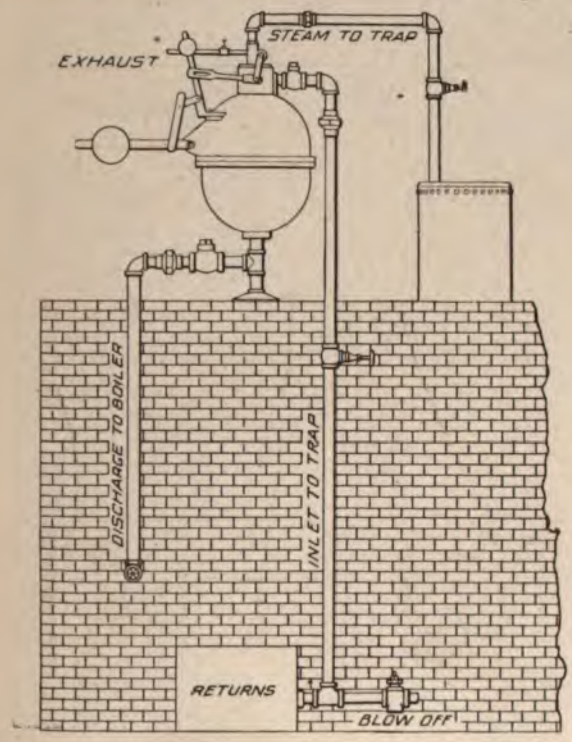


Fig. 124. Return Trap with Steam Valve Operated by Bucket or Float Inside.

Steam first passes from the boilers into a large drum or header. From this, a main, provided with a shut-off valve, is taken as shown; one branch is carried to the engines, while another is connected with the heating system through a reducing valve having a by-pass and cut-out valves. The exhaust from the engines connects with the large main over the boilers at a point just above the steam drum. The branch at the right is carried outboard through a back-pressure valve which may be set to carry any desired pressure on the system. The other branch at the left passes through an oil separator into the heating system. The connections between the mains and radiators are made in the usual way, and the main return is carried back to the return pump near the floor. A false water-line or seal is obtained by elevating the pump regulator as already described. An equalizing or balance pipe connects the top of the regulator with the low-pressure heating main, and high pressure is supplied to the pump as shown.

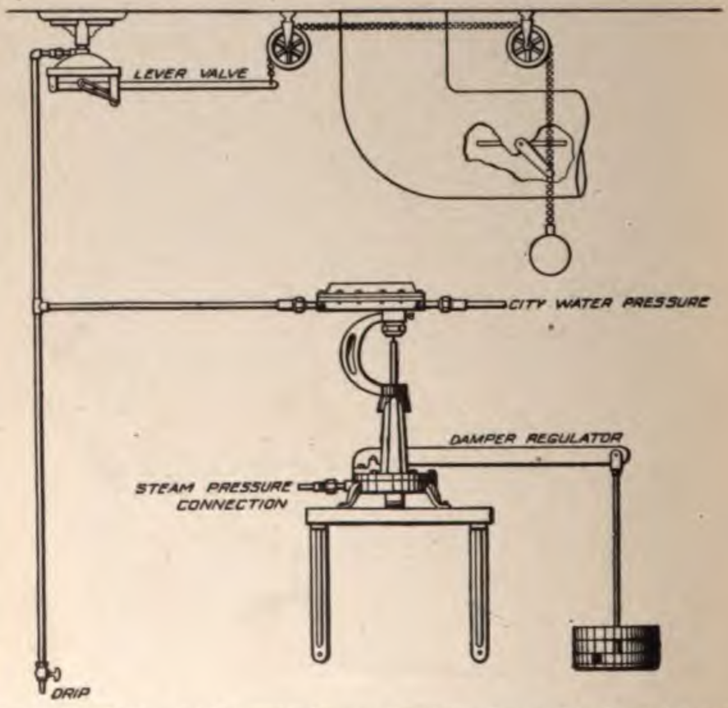


Fig. 125. Simple Form of Automatic Damper-Regulator, Operated by Lever Attached to Diaphragm, for Closing Dampers when Steam Pressure Reaches a Certain Point.

A sight-feed lubricator should be placed in this pipe above the automatic valve; and a valved by-pass should be placed around the regulator, for running the pump in case of accident or repairs. The oil separator should be drained through a special oil trap to a catch-basin or to the sewer; and the steam drum or any other low points or pockets in the high-pressure piping should be dripped to the return tank through suitable traps.

Means should be provided for draining all parts of the system to the sewer, and all traps and special apparatus should be by-passed. The return-pump should always be duplicated in a plant of any size, as a safeguard against accident; and the two pumps should be run alternately, to make sure that one is always in working order.

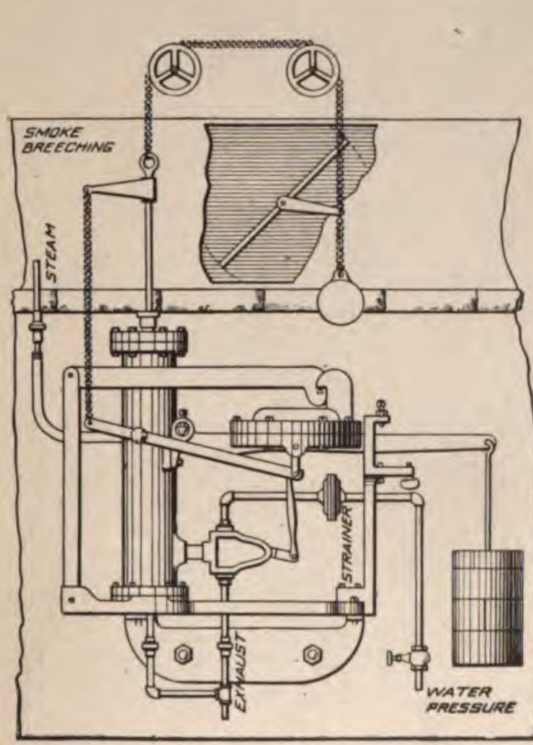


Fig. 126. Automatic Damper-Regulator Operated by Piston Actuated by Water-Pressure.

One piece of apparatus not shown in Fig. 127 is the feed-water heater. If all of the exhaust steam can be utilized for heating purposes, this is not necessary, as the cold water for feeding the boilers may be discharged into the return pipe and be pumped in with the condensation. In summertime, however, when the heating plant is not in use, a feed-water heater is necessary, as a large amount of heat

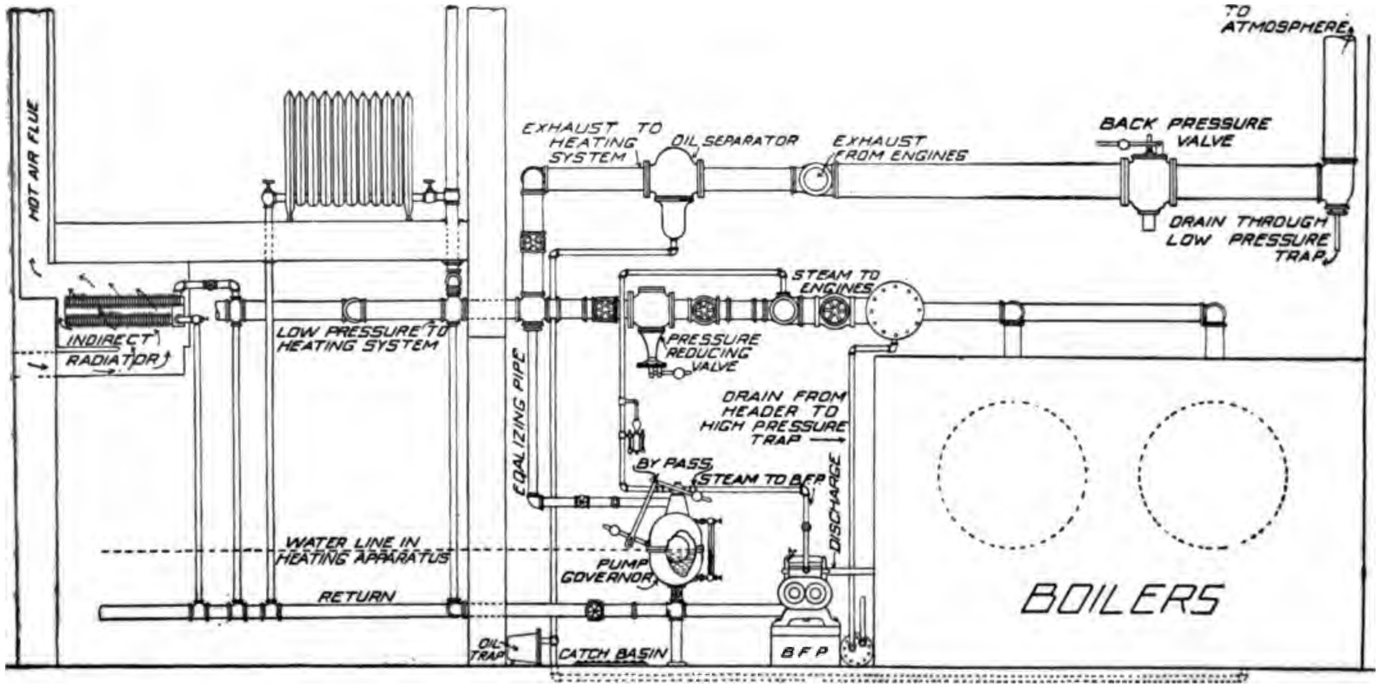
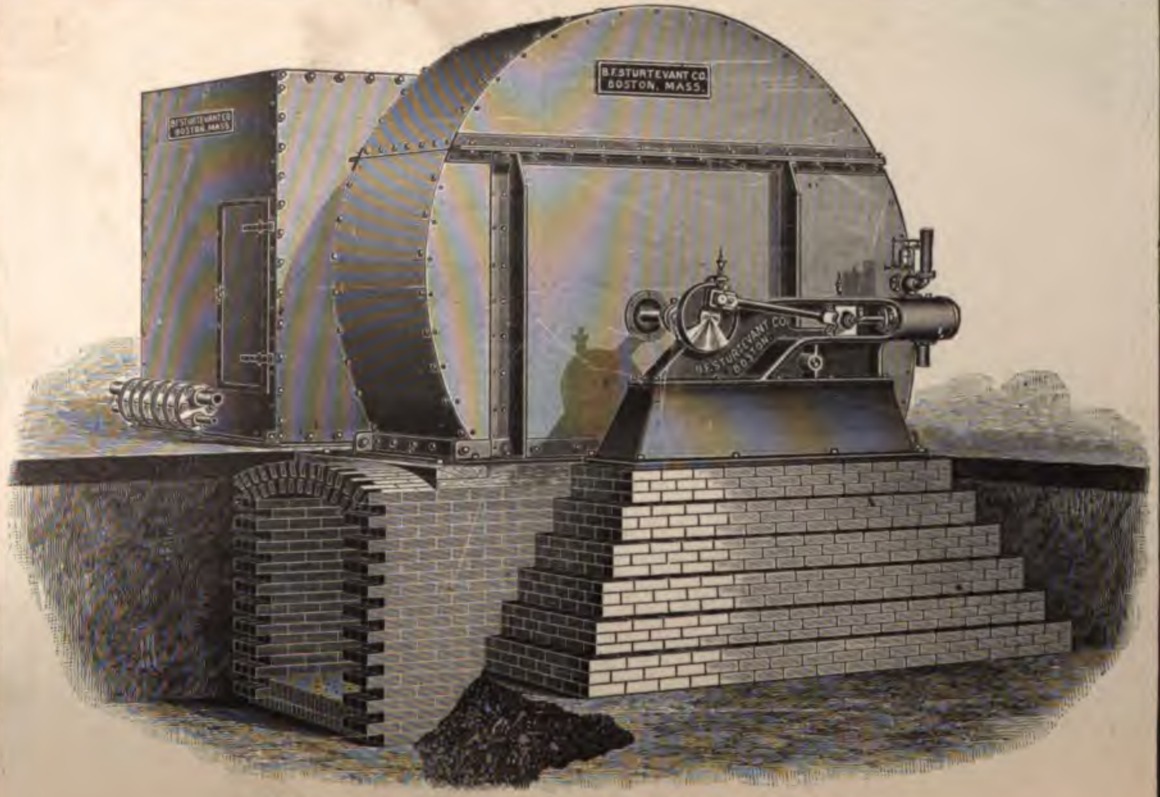


Fig. 127. General Method of Making Pipe Connections for Exhaust-Steam Heating.

which would otherwise be wasted may be saved in this way. The connections will depend somewhat upon the form of heater used; but in general a single connection with the heating main inside the back-pressure valve is all that is necessary. The condensation from the heater should be trapped to the sewer.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THE STURTEVANT STEAM HOT BLAST APPARATUS.
Three-Quarter Housing Steam Fan and Two-Group Corrugated Sectional Base Heater.

HEATING AND VENTILATION

PART III

VACUUM SYSTEMS

Low-Pressure or Vacuum Systems. In the systems of steam heating which have been described up to this point, the pressure carried has always been above that of the atmosphere, and the action of gravity has been depended upon to carry the water of condensation back to the boiler or receiver; the air in the radiators has been forced out through air-valves by the pressure of steam back of it. Methods will now be taken up in which the pressure in the heating system is less than the atmosphere, and where the circulation through the radiators is produced by suction rather than by pressure. Systems of this kind have several advantages over the ordinary methods of circulation under pressure. *First*—no back-pressure is produced at the engines when used in connection with exhaust steam; but rather there will be a reduction of pressure due to the partial vacuum existing in the radiators. *Second*—there is a complete removal of air from the coils and radiators, so that all portions are steam-filled and available for heating purposes. *Third*—there is complete drainage through the returns, especially those having long horizontal runs; and there is absence of water-hammer. *Fourth*—smaller return pipes may be used. The two older systems of this kind in common use are known as the Webster and Paul systems; other systems of recent introduction are described in the Instruction Paper on Steam and Hot-Water Fitting.

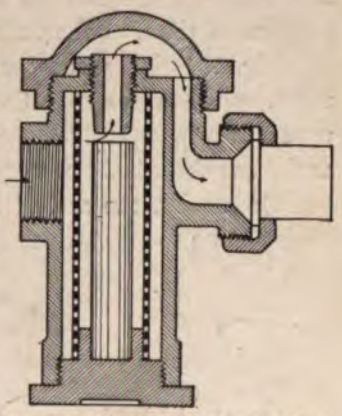

Fig. 128. Air Outlet-Valve for Radiator, Automatically Operated by Expansion and Contraction of Vulcanite Stem.

Webster System. This consists primarily of an automatic outlet-valve on each coil and radiator, connected with some form of suction apparatus such as a pump or ejector. One type of valve used is shown in section in Fig. 128, which replaces the usual hand-valve at the return end of the radiator. It is similar in construction to some of the air-valves already described, consisting of a rubber or vulcanite stem closing against a valve opening when made to expand by the presence of steam. When water or air fills the valve, the stem contracts and allows it to be sucked out as shown by the arrows. A perforated metal strainer surrounds the stem or expansion piece, to prevent dirt and sediment from clogging the valve.

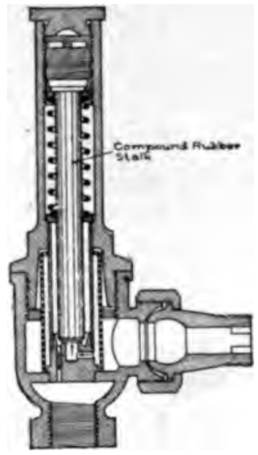

Fig. 129. Thermostat Attached to Angle-Valve with Top Removed.

Fig. 129 shows the valve—or *thermostat*, as it is called—attached to an ordinary angle-valve with the top removed; and Fig. 130 indicates the method of draining the bottoms of risers or the ends of mains.

Fig. 131 shows another form of this valve, called a *water-seal motor*. This is used under practically the same conditions as the one described above. Its action is as follows:

Ordinarily, the seal *A* is down, and the central tube-valve is resting upon the seat, closing the port *K* and preventing direct communication between the interior of the motor-body *E* and the outlet *L*. The outlet is attached to a pipe leading to a vacuum-pump, or other draining apparatus, which exhausts the space *F* above the seal through the annular space between the spindle *B* and the inside of the central tube *G*. The water of condensation, accumulating in the radiator or coil, passes into the chamber *E*, through the inlet *C*, rises in the chamber, and seals the space between the seal-shell *A* and the sleeve of the bonnet *D*. The differential pressure thus created causes the seal *A* to rise, lifting the end of the central tube off the seat, thus opening a clear passageway for the ejection of the water of condensation.

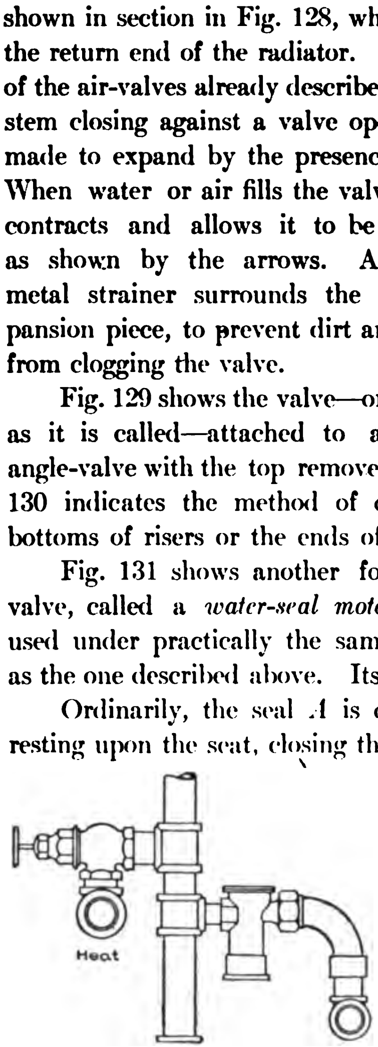

Fig. 130. Showing Method of Draining Bottoms of Risers or Ends of Mains.

When all the water of condensation has been drawn out of the radiator, the seal and tube are reseated by gravity, thus closing the port *K*, preventing waste or loss of steam; and the pressure is equalized above and below the seal because of the absence of water. This action is practically instantaneous. When the condensation is small in quantity, the discharge is intermittent and rapid.

The space between the seal *A* and the sleeve of the bonnet *D*, and the annular space between the central tube *G* and the spindle *B*, form a passageway through which the air is continually withdrawn by the vacuum pump or other draining apparatus.

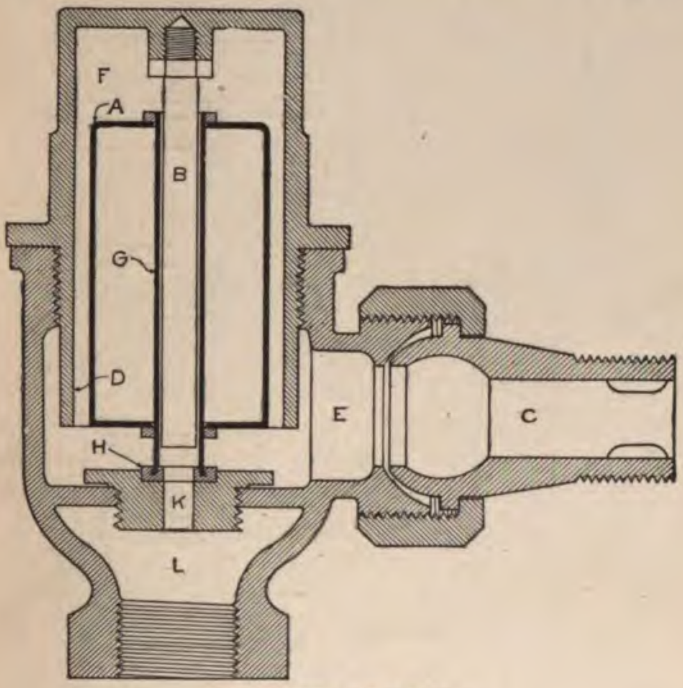

Fig. 131. Water-Seal Motor.

The action outlined continues as long as water is present.

No adjustment whatever is necessary; the motor is entirely automatic.

One special advantage claimed for this system is that the amount of steam admitted to the radiators may be regulated to suit the requirements of outside temperature; and is possible without water-

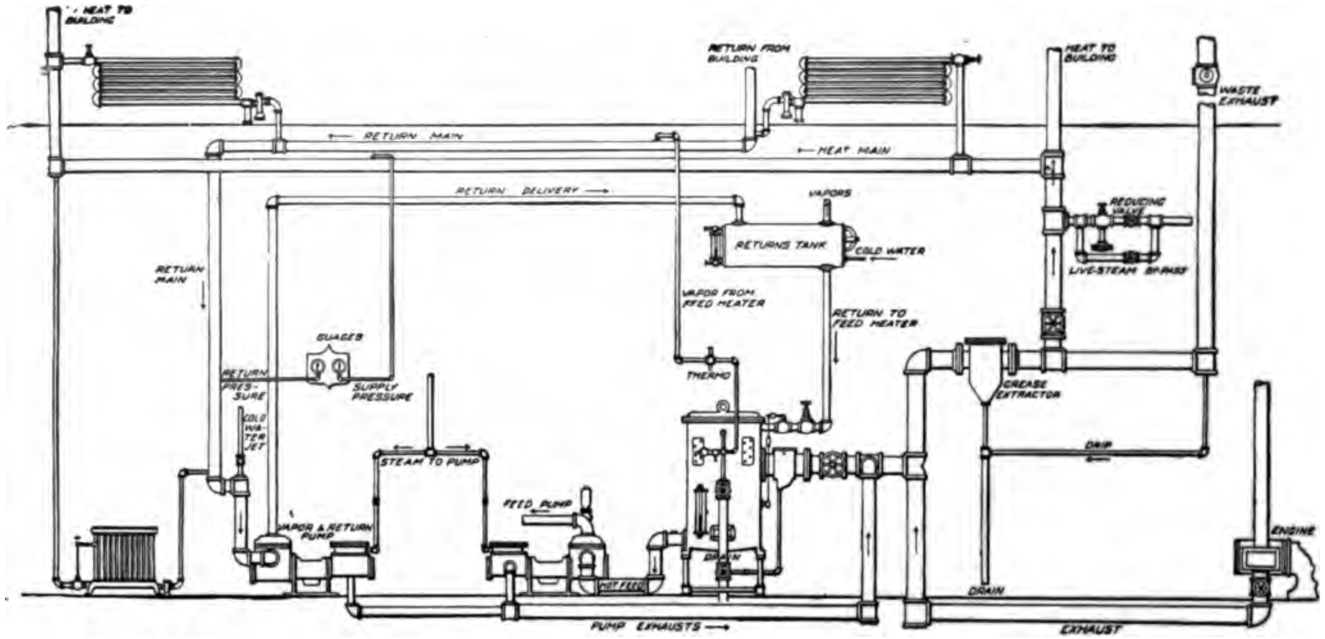

Fig. 132. Showing General Application of Webster System to Exhaust-Steam Heating.

logging or hammering. This may be done at will by closing down on the inlet supply to the desired degree. The result is the admission of a smaller amount of steam to the radiator than it is calculated to condense normally. The condensation is removed as fast as formed, by the opening of the thermostatic valve.

The general application of this system to exhaust heating is shown in Fig. 132. Exhaust steam is brought from the engine as shown; one branch is connected with a feed-water heater, while the other is carried upward and through a grease extractor, where it branches again, one line leading outboard through a back-pressure valve and the other connecting with the heating main. A live steam connection is made through a reducing valve, as in the ordinary system. Valved connections are made with the coils and radiators in the usual manner; but the return valves are replaced by the special thermostatic valves described above.

The main return is brought down to a vacuum pump which discharges into a *return tank*, where the air is separated from the water and passes off through the vapor pipe at the top. The condensation then flows into the feed-water heater, from which it is automatically pumped back into the boilers. The cold-water feed supply is connected with the return tank, and a small cold-water jet is connected into the suction at the vacuum pump for increasing the vacuum in the heating system by the condensation of steam at this point.

Paul System. In this system the suction is connected with the air-valves instead of the returns, and the vacuum is produced by means of a steam ejector instead of a pump. The returns are carried back to a receiving tank, and pumped back to the boiler in the usual manner. The ejector in this case is called the *exhauster*.

Fig. 133 shows the general method of making the pipe connections with the radiators in this system; and Fig. 134, the details of connection at the exhauster.

A A are the returns from the air-valves, and connect with the exhausters as shown. Live steam is admitted in small quantities through the valves *B B*; and the mixture of air and steam is discharged outboard through the pipe *C*. *D D* are gauges showing the pressure in the system; and *E E* are check-valves. The advantage of this system depends principally upon the quick removal of air from the various radiators and pipes, which constitutes the principal obstruction to circulation; the inductive action in many cases is sufficient to cause the system to operate somewhat below atmospheric pressure.

Where exhaust steam is used for heating, the radiators should be somewhat increased in size, owing to the lower temperature of the steam. It is common practice to add from 20 to 30 per cent to the sizes required for low-pressure live steam.

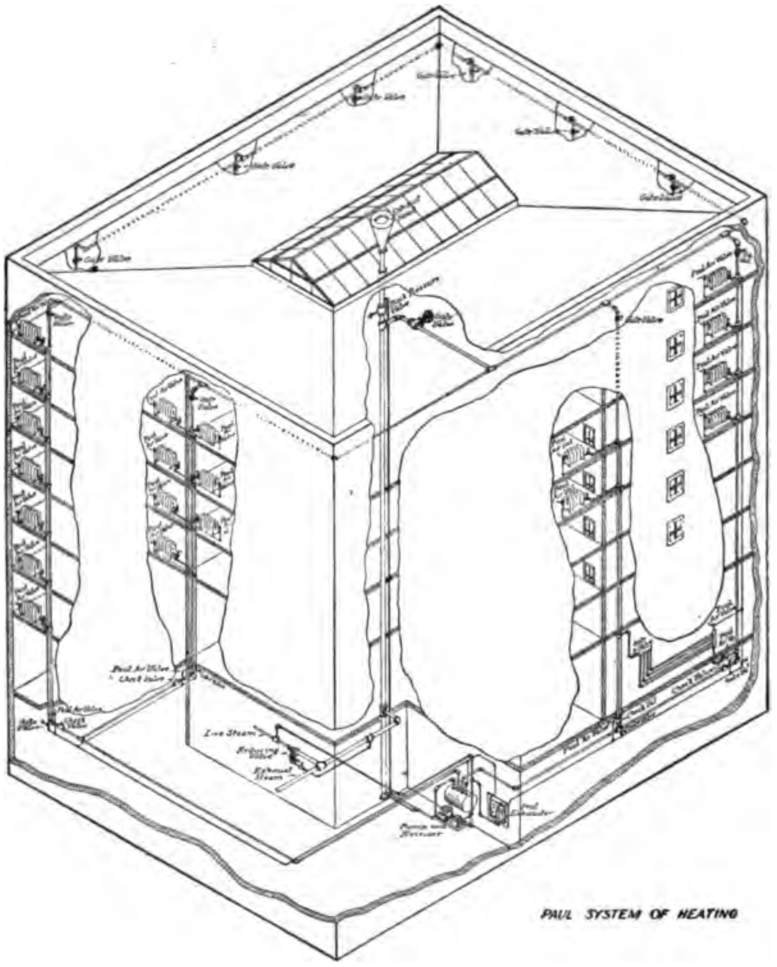

Fig. 133. Showing General Method of Making Pipe and Radiator Connections in Paul System.

FORCED BLAST

In a system of forced circulation by means of a fan or blower the action is positive and practically constant under all usual conditions of outside temperature and wind action. This gives it a decided advantage over natural or gravity methods, which are affected to a greater or less degree by changes in wind-pressure, and makes it especially adapted to the ventilation and warming of large buildings such as shops, factories, schools, churches, halls, theaters, etc., where large and definite air-quantities are required.

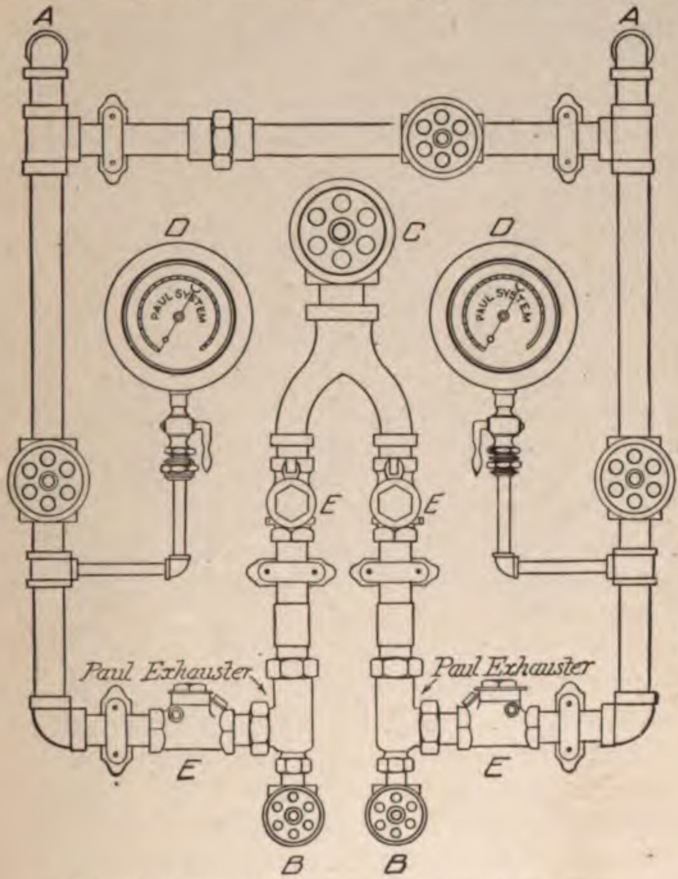

Fig. 134. Details of Connections at Exhauster, Paul System.

Exhaust Method. This consists in drawing the air out of a building, and providing for the heat thus carried away by placing steam coils under windows or in other positions where the inward leakage is supposed to be the greatest. When this method is used, a partial vacuum is created within the building or room, and all currents and leaks are inward; there is nothing to govern definitely the quality and place of introduction of the air, and it is difficult to provide suitable means for warming it.

Plenum Method. In this case the air is forced into the building, and its quality, temperature, and point of admission are completely under control. All spaces are filled with air under a slight pressure, and the leakage is outward, thus preventing the drawing of foul air into the room from any outside source. But above all, ample opportunity is given for properly warming the air by means of heaters, either in direct connection with the fan or in separate passages leading to the various rooms.

Form of Heating Surface. The best type of heater for any particular case will depend upon the volume and final temperature of the air, the steam pressure, and the available space. When the air is to be heated to a high temperature for both warming and ventilating a building, as in the case of a shop or mill, heaters of the general form shown in Figs. 135, 136, and 137 are used. These may also be adapted to all classes of work by varying the proportions as required. They can be made shallow and of large superficial area, for the comparatively low temperatures used in purely ventilating work; or deeper, with less height and breadth, as higher temperatures are required.

Fig. 135 shows in section a heater of this type, and illustrates the circulation of steam through it. It consists of sectional cast-iron bases with loops of wrought-iron pipe connected as shown. The steam enters the upper part of the bases or headers, and passes up one side of the loops, then across the top and down on the other side, where the condensation is taken off through the return drip, which is separated from the inlet by a partition. These heaters are made up in sections of 2 and 4 rows of pipes each. The height varies from 3½ to 9 feet, and the width from 3 feet to 7 feet in the standard sizes. They are usually made up of 1-inch pipe, although 1¼-inch is commonly used in the larger sizes. Fig. 136 shows another form; in this case all the loops are made of practically the same length by the special form of construction shown. This is claimed to prevent the short-circuiting of steam through the shorter loops, which causes the outer pipes to remain cold. This form of heater is usually encased in a sheet-steel housing as shown in Fig. 137, but may be supported on a foundation between brick walls if desired.

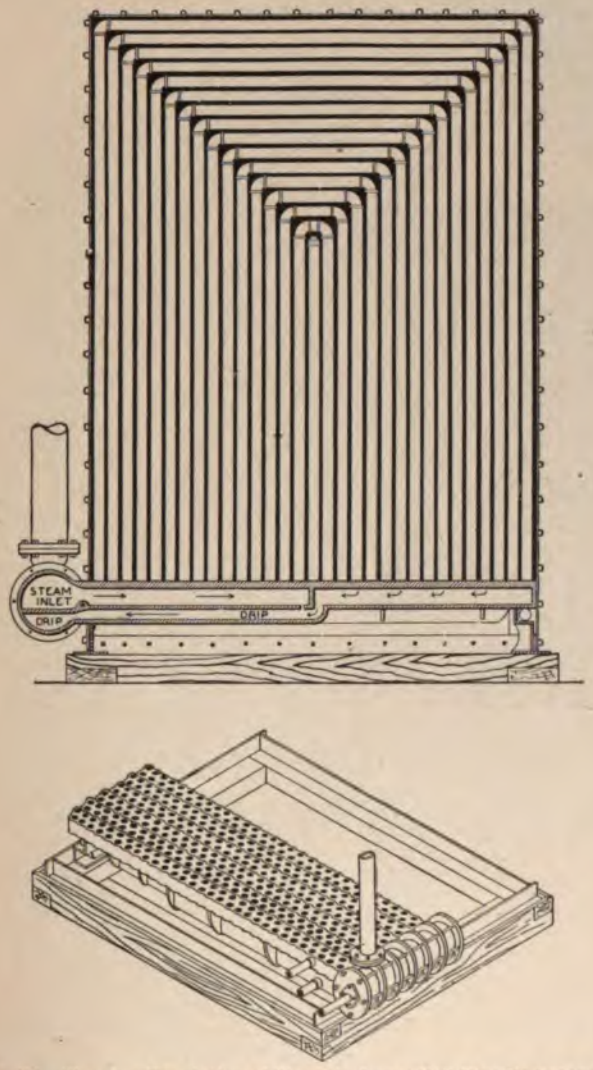

Fig. 135. Showing Circulation of Steam in Large Coil-Pipe Radiator for Heating Mills, Shops, etc.

Fig. 138 shows a special form of heater particularly adapted to ventilating work where the air does not have to be raised above 70 or 80 degrees. It is made up of 1-inch wrought-iron pipe connected with supply and return headers; each section contains 14 pipes, and they are usually made up in groups of 5 sections each. These coils are supported upon tee-irons resting upon a brick foundation. Heat-

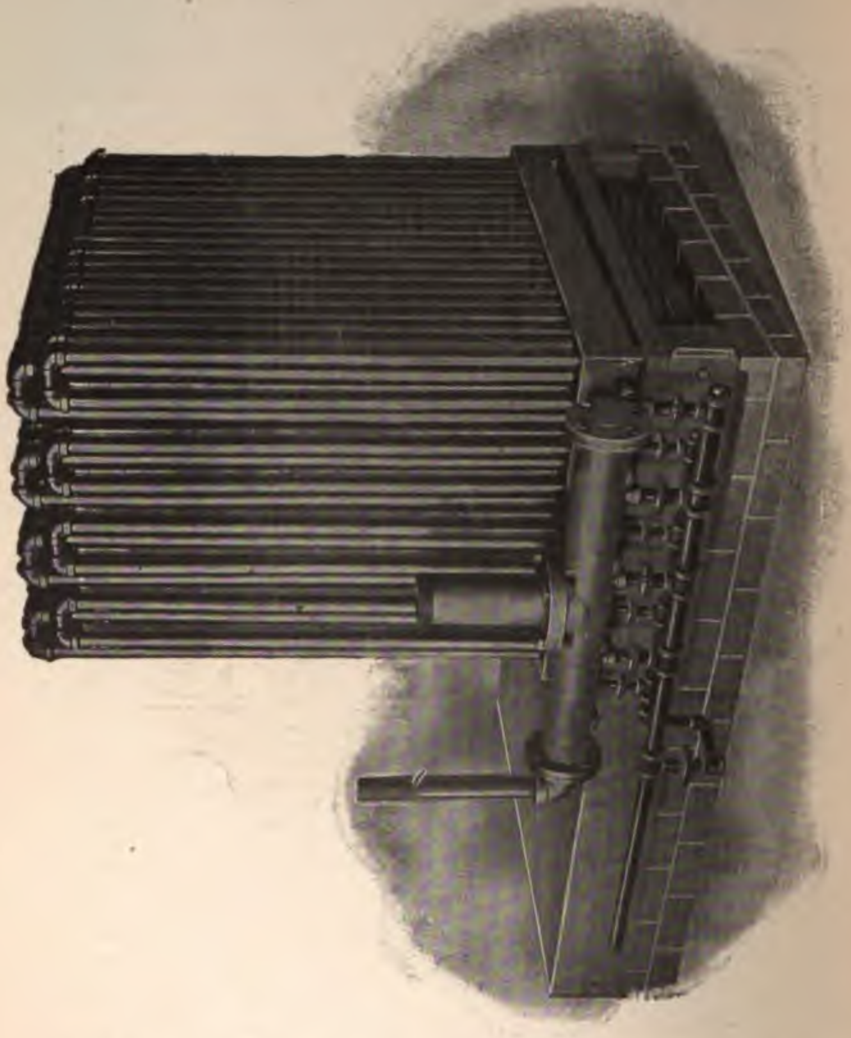

Fig. 136. Another Type of Large Coil Radiator for Mills, Factories, etc.

ers of this form are usually made to extend across the side of a room with brick walls at the sides, instead of being encased in steel housings.

Fig. 139 shows a front view of a cast-iron sectional heater for use under the same conditions as the pipe heaters already described. This heater is made up of several banks of sections, like the one shown in the cut, and enclosed in a steel-plate casing.

Cast-iron indirect radiators of the pin type are well adapted for use in connection with mechanical ventilation, and also for heating where the air-volume is large and the temperature not too high, as in churches and halls. They make a convenient form of heater for schoolhouse and similar work, for, being shallow, they can be supported upon I-beams at such an elevation that the condensation will be returned to the boilers by gravity.

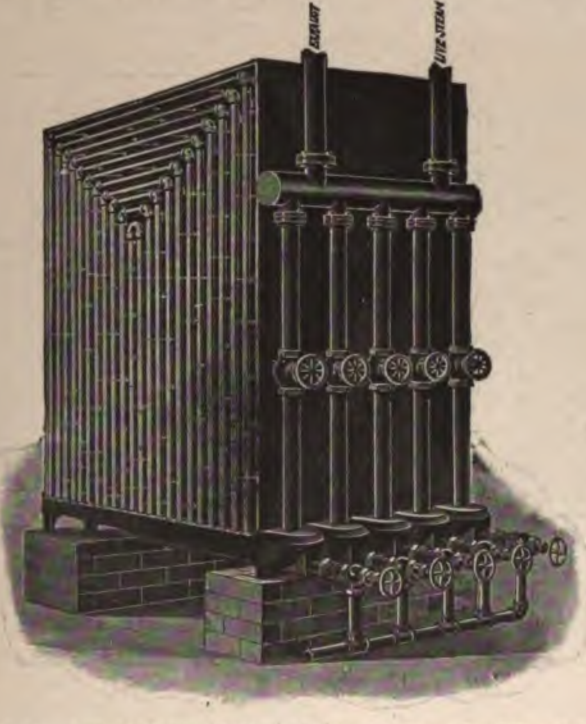

Fig. 137. Large Coil-Pipe Radiator Encased in Sheet-Steel Housing.

In the case of vertical pipe heaters, the bases are below the water-line of the boilers, and the condensation must be returned by the use of pumps and traps.

Efficiency of Pipe Heaters. The efficiency of the heaters used in connection with forced blast varies greatly, depending upon the temperature of the entering air, its velocity between the pipes, the temperature to which it is raised, and the steam pressure carried in the heater. The general method in which the heater is made up is also an important factor.

In designing a heater of this kind, care must be taken that the free area between the pipes is not contracted to such an extent that an excessive velocity will be required to pass the given quantity of air through it. In ordinary work it is customary to assume a velocity of 800 to 1,000 feet per minute; higher velocities call for a greater pressure on the fan, which is not desirable in ventilating work.

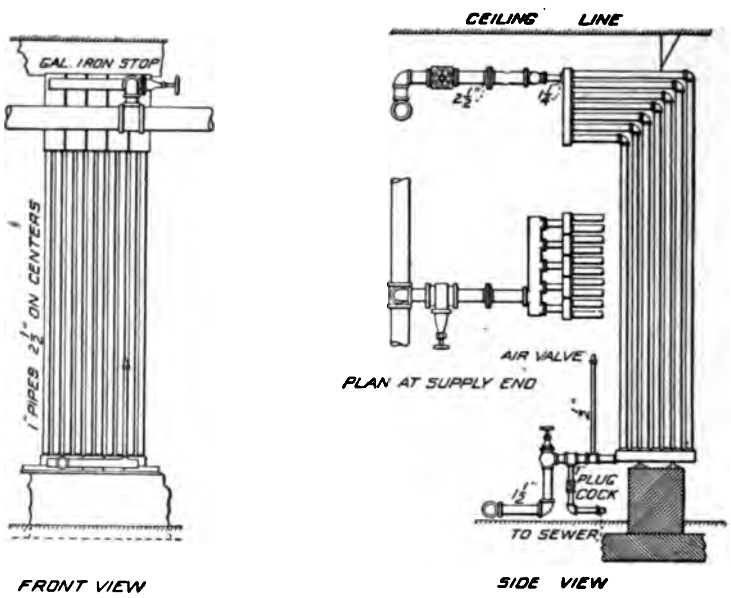

Fig. 138. Heater Especially Adapted to Ventilation where Air does not Have to be Heated above 70 to 80 degrees F.

In the heaters shown, about .4 of the total area is free for the passage of air; that is, a heater 5 feet wide and 6 feet high would have a total area of 5 × 6 = 30 square feet, and a free area between the pipes of 30 × .4 = 12 square feet. The depth or number of rows of pipe does not affect the free area, although the friction is increased and additional work is thrown upon the fan. The efficiency in any given heater will be increased by increasing the velocity of the air through it; but the final temperature will be diminished; that is, a larger quantity of air will be heated to a lower temperature in the second case, and, while the total heat given off is greater, the air-quantity increases more rapidly than the heat-quantity, which causes a drop in temperature.

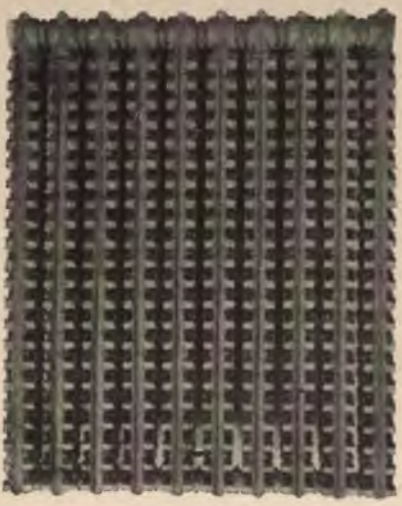

Fig. 139. Front View of Cast-Iron Sectional Heater. The Banks of Sections are Enclosed in a Steel-Plate Casing.

Increasing the number of rows of pipe in a heater, with a constant air-quantity, increases the final temperature of the air, but diminishes the efficiency of the heater, because the average difference in temperature between the air and the steam is less. Increasing the steam pressure in the heater (and consequently its temperature) increases both the final temperature of the air and the efficiency of the heater. Table XXX has been prepared from different tests, and may be used as a guide in computing probable results under ordinary working conditions. In this table it is assumed that the air enters the heater at a temperature of zero and passes between the pipes with a velocity of 800 feet per minute. Column 1 gives the number of rows of pipe in the heater, ranging from 4 to 20 rows; and columns 2, 3, and 4, show the final temperature to which the entering air will be raised from zero under various pressures. Under 5 pounds pressure, for example, the rise in temperature ranges from 30 to 140 degrees; under 20 pounds, 35 to 150 degrees; and under 60 pounds, 45 to 170 degrees. Columns 5, 6, and 7 give approximately the corresponding efficiency of the heater. For example, air passing through a heater 10 pipes deep and carrying 20 pounds pressure, will be raised to a temperature of 90 degrees, and the heater will have an efficiency of 1,650 B. T. U. per square foot of surface per hour.

TABLE XXX

Data Concerning Pipe Heaters

Temperature of entering air, zero.—Velocity of air between the pipes, 800 feet per minute.

Rows of Pipe Deep	Temperature to which Air will be Raised from Zero			Efficiency of Heating Surface in B. T. U., per Square Foot per Hour		
	Steam Pressure in Heater			Steam Pressure in Heater		
	5 lbs.	20 lbs.	60 lbs.	5 lbs.	20 lbs.	60 lbs.
4	30	35	45	1,600	1,800	2,000
6	50	55	65	1,600	1,800	2,000
8	65	70	85	1,500	1,650	1,850
10	80	90	105	1,500	1,650	1,850
12	95	105	125	1,500	1,650	1,850
14	105	120	140	1,400	1,500	1,700
16	120	130	150	1,400	1,500	1,700
18	130	140	160	1,300	1,400	1,600
20	140	150	170	1,300	1,400	1,600

For a velocity of 1,000 feet, multiply the *temperatures* given in the table by .9, and the *efficiencies* by 1.1.

Example. How many square feet of radiation will be required to raise 600,000 cubic feet of air per hour from zero to 80 degrees, with a velocity through the heater of 800 feet per minute and a steam pressure of 5 pounds? What must be the total area of the heater front, and how many rows of pipes must it have?

Referring back to the formula for heat required for ventilation, we have

$$\frac{600{,}000 \times 80}{55} = 872{,}727 \text{ B. T. U. required.}$$

Referring to Table XXX, we find that for the above conditions a heater 10 pipes deep is required, and that an efficiency of 1,500 B. T. U. will be obtained. Then $\frac{872{,}727}{1{,}500} = 582$ square feet of surface required, which may be taken as 600 in round numbers. $\frac{600{,}000}{60} = 10{,}000$ cubic feet of air per minute; and $\frac{10{,}000}{800} = 12.5$ square feet of free area required through the heater. If we assume .4 of the total heater front to be free for the passage of air, then $\frac{12.5}{.4} = 31$ square feet, the total area required.

For convenience in estimating the approximate dimensions of a heater, Table XXXI is given. The standard heaters made by different manufacturers vary somewhat, but the dimensions given in the table represent average practice. Column 3 gives the square feet of heating surface in a single row of pipes of the dimensions given in columns 1 and 2; and column 4 gives the free area between the pipes.

TABLE XXXI

Dimensions of Heaters

WIDTH OF SECTION	HEIGHT OF PIPES	SQUARE FEET OF SURFACE	FREE AREA THROUGH HEATER IN SQ. FT.
3 feet	3 feet 6 inches	20	4.2
3 "	4 " 0 "	22	4.8
3 "	4 " 6 "	25	5.4
3 "	5 " 0 "	28	6.0
4 "	4 " 6 "	34	7.2
4 "	5 " 0 "	38	8.0
4 "	5 " 6 "	42	8.8
4 "	6 " 0 "	45	9.6
5 "	5 " 6 "	52	11.0
5 "	6 " 0 "	57	12.0
5 "	6 " 6 "	62	13.0
5 "	7 " 0 "	67	14.0
6 "	6 " 6 "	75	15.6
6 "	7 " 0 "	81	16.8
6 "	7 " 6 "	87	18.0
6 "	8 " 0 "	92	19.2
7 "	7 " 6 "	98	21.0
7 "	8 " 0 "	108	22.4
7 "	8 " 6 "	109	23.8
7 "	9 " 0 "	116	25.2

In calculating the total height of the heater, add 1 foot for the base.

These sections are made up of 1-inch pipe, except the last or 7-foot sections, which are made of 1¼-inch pipe.

Using this table in connection with the example just given, we should look in the last column for a section having a free area of 12.5 square feet; here we find that a 5 feet by 6 feet 6 inches section has a free opening of 13 square feet and a radiating surface of 62 square feet. The conditions call for 10 rows of pipes and 10 × 62 = 620 square feet of radiating surface, which is slightly more than called for, but which would be near enough for all practical purposes.

EXAMPLE FOR PRACTICE

Compute the dimensions of a heater to warm 20,000 cubic feet of air per minute from 10 below zero to 70 degrees above, with 5 pounds steam pressure.

Ans. 1,164 sq. ft. of rad. surface 10 pipes deep.
25 sq. ft. free area through heater.

Use twenty 5 ft. by 6 ft. sections, side by side, which gives 24 square feet area and 1,140 square feet of surface.

The general method of computing the size of heater for any given building is the same as in the case of indirect heating. First obtain the B. T. U. required for ventilation, and to that add the heat loss through walls, etc.; and divide the result by the efficiency of the heater under the given conditions.

Example. An audience hall is to be provided with 400,000 cubic feet of air per hour. The heat loss through walls, etc., is 250,000 B.T.U. per hour in zero weather. What will be the size of heater, and how many rows of pipe deep must it be, with 20 pounds steam pressure?

$$\frac{400,000 \times 70}{55} = 509,090 \text{ B. T. U. for ventilation.}$$

Therefore 250,000 + 509,090 = 759,090 B. T. U., total to be supplied.

We must next find to what temperature the entering air must be raised in order to bring in the required amount of heat, so that the number of rows of pipe in the heater may be obtained and its corresponding efficiency determined. We have entering the room for purposes of ventilation, 400,000 cubic feet of air every hour, at a temperature of 70 degrees; and the problem now becomes: To what temperature must this air be raised to carry in 250,000 B. T. U. additional for warming?

We have learned that 1 B. T. U. will raise 55 cubic feet of air 1 degree. Then 250,000 B. T. U. will raise 250,000 × 55 cubic feet of air 1 degree.

$$\frac{250,000 \times 55}{400,000} = 34 +$$

The air in this case must be raised to 70 + 34 = 104 degrees, to provide for both ventilation and warming. Referring to Table XXX, we find that a heater 12 pipes deep will be required, and that the corresponding efficiency of the heater will be 1,650 B. T. U. Then $\frac{759,090}{1,650}$ = 460 square feet of surface required.

Efficiency of Cast-Iron Heaters. Heaters made up of indirect pin radiators of the usual depth, have an efficiency of at least 1,500 B. T. U., with steam at 10 pounds pressure, and are easily capable of warming air from zero to 80 degrees or over when computed on this basis. The free space between the sections bears such a relation to the heating surface that ample area is provided for the flow of air through the heater, without producing an excessive velocity.

The heater shown in Fig. 139 may be counted on for an efficiency at least equal to that of a pipe heater; and in computing the depth, one row of sections may be taken as representing 4 rows of pipe.

Pipe Connections. In the heater shown in Fig. 135, all the sections take their supply from a common header, the supply pipe connecting with the top, and the return being taken from the lower division at the end, as shown.

In Fig. 137 the base is divided into two parts, one for live steam, and the other for exhaust. The supply pipes connect with the upper compartments, and the drips are taken off as shown. Separate traps should be provided for the two pressures.

The connections in Fig. 136 are similar to those just described, except that the supply and return headers, or bases, are drained through separate pipes and traps, there being a slight difference in pressure between the two, which is likely to interfere with the proper drainage if brought into the same one. This heater is arranged to take exhaust steam, but has a connection for feeding in live steam through a reducing valve if desired, the whole heater being under one pressure.

In heating and ventilating work where a close regulation of temperature is required, it is usual to divide the heater into several sections, depending upon its size, and to provide each with a valve in the supply and return. In making the divisions, special care should be taken to arrange for as many combinations as possible. For example, a heater 10 pipes deep may be made up of three sections—one of

2 rows, and two of 4 rows each. By means of this division, 2, 4, 6, 8, or 10 rows of pipe can be used at one time, as the outside weather conditions may require.

When possible, the return from each section should be provided with a water-seal two or three feet in depth. In the case of overhead heaters, the returns may be sealed by the water-line of the boiler or by the use of a special water-line trap; but vertical pipe heaters resting on foundations near the floor are usually provided with siphon loops extending into a pit. If this arrangement is not convenient, a separate trap should be placed on the return from each section. The main return, in addition to its connection with the boiler or pump receiver, should have a connection with the sewer for blowing out when steam is first turned on. Sometimes each section is provided with a connection of this kind.

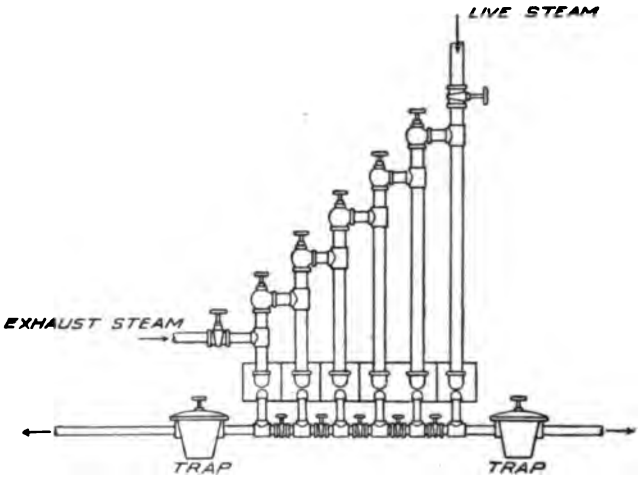

Fig. 140. Heater Made Up of Interchangeable Sections.

Large automatic air-valves should be connected with each section; and it is well to supplement these with a hand pet-cock, unless individual blow-off valves are provided as described above.

If the fan is driven by a steam engine, provision should be made for using the exhaust in the heater; and part of the sections should be so valved that they may be supplied with either exhaust or live steam.

Fig. 140 shows an arrangement in which all of the sections are interchangeable.

From 50 to 60 square feet of radiating surface should be provided in the exhaust portion of the heater for each engine horse-power, and should be divided into at least three sections, so that it can be proportioned to the requirements of different outside temperatures.

Pipe Sizes. The sizes of the mains and branches may be computed from the tables already given in Part II, taking into account the higher efficiency of the heater and the short runs of piping.

Table XXXII, based on experience, has been found to give satisfactory results when the apparatus is near the boilers. If the main supply pipe is of considerable length, its diameter should be checked by the method previously given.

TABLE XXXII

Pipe Sizes

Square Feet of Surface	Diameter of Steam Pipe	Diameter of Return
150	2 inches	1¼ inches
300	2½ "	1½ "
500	3 "	2 "
700	3½ "	2 "
1,000	4 "	2½ "
2,000	5 "	2½ "
3,000	6 "	3 "

Heaters of the patterns shown in Figs. 135, 136, and 137 are usually tapped at the factory for high or low pressure as desired, and these sizes may be followed in making the pipe connections.

The sizes marked on Fig. 136 may be used for all ordinary work where the pressure runs from 5 to 20 pounds; for pressures above that, the supply connections may be reduced one size.

FANS

There are two types of fans in common use, known as the *centrifugal fan* or *blower*, and the *disc fan* or *propeller*. The former consists of a number of straight or slightly curved blades extending radially from an axis, as shown in Fig. 141. When the fan is in motion, the air in contact with the blades is thrown outward by the action of centrifugal force, and delivered at the circumference or periphery of the wheel. A partial vacuum is thus produced at the center of the wheel, and air from the outside flows in to take the place of that which has been discharged.

Fig. 142 illustrates the action of a centrifugal fan, the arrows showing the path of the air. This type of fan is usually enclosed in a steel-plate casing of such form as to provide for the free movement of the air as it escapes from the periphery of the wheel. An opening in the circumference of the casing serves as an outlet into the distributing ducts which carry the air to the various rooms to be ventilated.

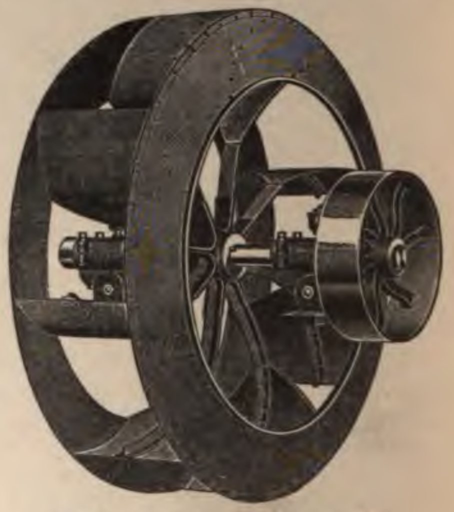
Fig. 141. Centrifugal Fan or Blower.

A fan with casing, is shown in Fig. 143; and a combined heater and fan, with direct-connected engine, is shown in Fig. 144.

The discharge opening can be located in any position desired, either up, down, top horizontal, bottom horizontal, or at any angle.

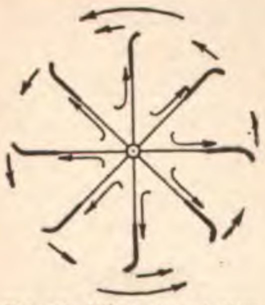
Fig. 142. Illustrating Action of Centrifugal Fan. The Arrows Show the Path of the Air.

Where the height of the fan room is limited, a form called the *three-quarter housing* may be used, in which the lower part of the casing is replaced by a brick or cemented pit extending below the floor-level as shown in Fig. 145.

Another form of centrifugal fan is shown in Fig. 146. This is known as the *cone fan,* and is commonly placed in an opening in a brick wall, and discharges air from its entire periphery into a room called a *plenum chamber,* with which the various distributing ducts connect.

This fan is often made double by placing two wheels back to back and surrounding them with a steel casing in a similar manner to the one shown in Fig. 143.

Cone fans are particularly adapted to church and schoolhouse work, as they are capable of moving large volumes of air at moderate speeds.

Fig. 147 shows a form of small direct-connected exhauster commonly used for ventilating toilet-rooms, chemical hoods, etc.

Centrifugal fans are used almost exclusively for supplying air for the ventilation of buildings, and for forced-blast heating. They are also used as exhausters for removing the air from buildings in cases where there is considerable resistance due to the small size or excessive length of the discharge ducts.

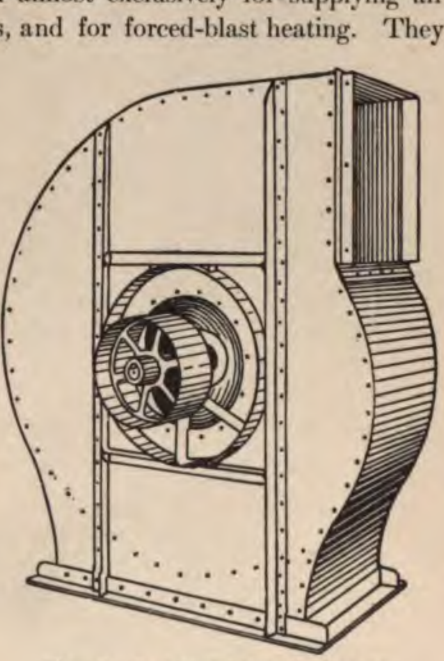

Fig. 143. Centrifugal Fan with Casing.

General Proportions. The general form of a fan wheel is shown in Fig. 141, which represents a single spider wheel with curved blades. Those over 4 feet in diameter usually have two spiders, while fans of large size are often provided with three or more. The number of floats or blades commonly varies from six to twelve, depending upon the diameter of the fan. They are made both curved and straight; the former, it is claimed, run more quietly, but, if curved too much, will not work so well against a high pressure as the latter form.

The relative proportions of a fan wheel vary somewhat in the case of different makes. The following are averages taken from fans of different sizes as made by several well-known manufacturers for general ventilating and similar work:

Width of fan at center = Diameter × .52
Width of fan at perimeter = Width at center × .8
Diameter of inlet = Diameter of wheel × .68

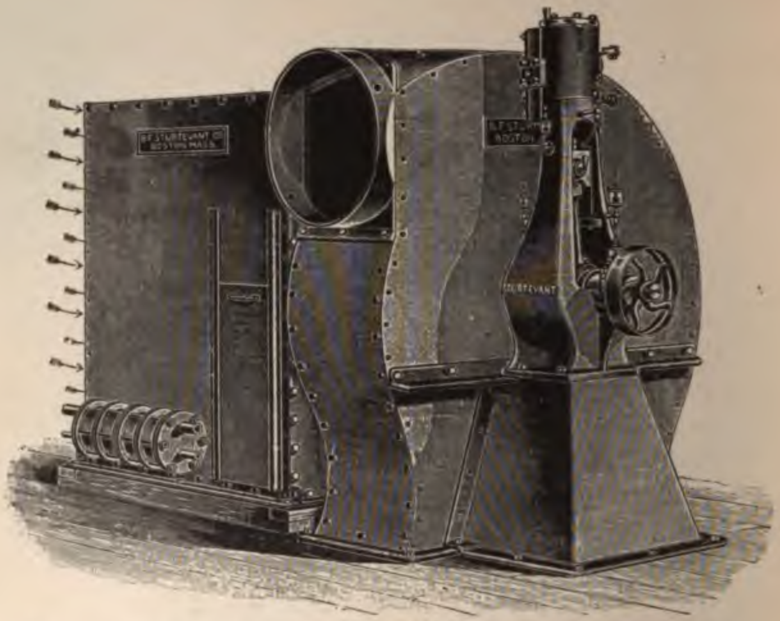
B.F. STURTEVANT CO.
BOSTON MASS.
STURTEVANT

Fig. 144. Combined Heater and Centrifugal Fan with Direct-Connected Engine.

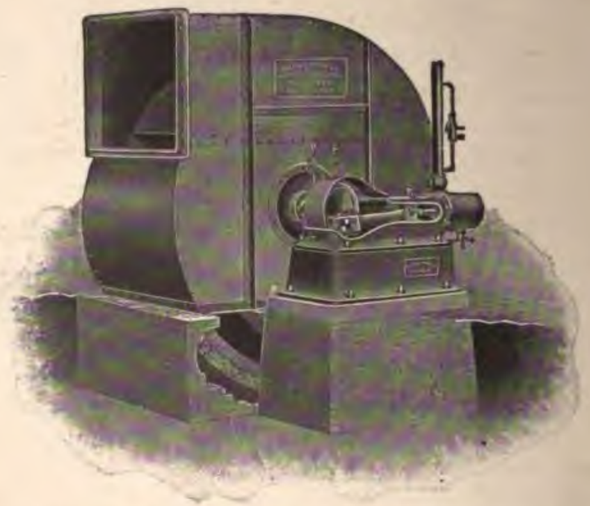

Fig. 145. Centrifugal Fan in "Three-Quarter Housing." Used where Headroom is Limited; Extra Space Provided by Pit under Floor-Level.

Fans are made both with double and with single inlets, the former being called *blowers* and the latter *exhausters*. The size of a fan is commonly expressed in inches, which means the approximate height of the casing of a full-housed fan. The diameter of the wheel is usually expressed in feet, and can be found in any given case by dividing the size in inches by 20. For example, a 120-inch fan has a wheel 120 ÷ 20 = 6 feet in diameter.

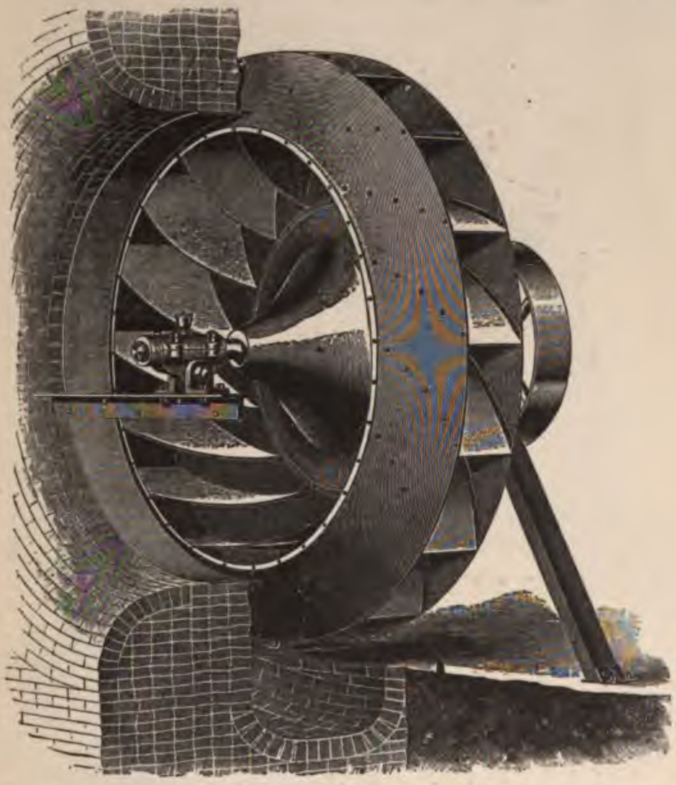

Fig. 146. "Cone" Fan. Discharges through Opening in Wall into a "Plenum Chamber" Connecting with Distributing Ducts.

Theory of Centrifugal Fans. The action of a fan is affected to such an extent by the various conditions under which it operates, that it is impossible to give fixed rules for determining the exact results to be expected in any particular instance. This being the case, it seems best to take up the matter briefly from a theoretical standpoint, and then show what corrections are necessary in the case of a given fan under actual working conditions.

There are various methods for determining the capacity of a fan at different speeds, and the power necessary to drive it; each manufacturer has his own formulæ for this purpose, based upon tests of his own particular fans. The methods given here apply in a general way to fans having proportions which represent the *average* of several standard makes; and the results obtained will be found to correspond well with those obtained in practice under ordinary conditions.

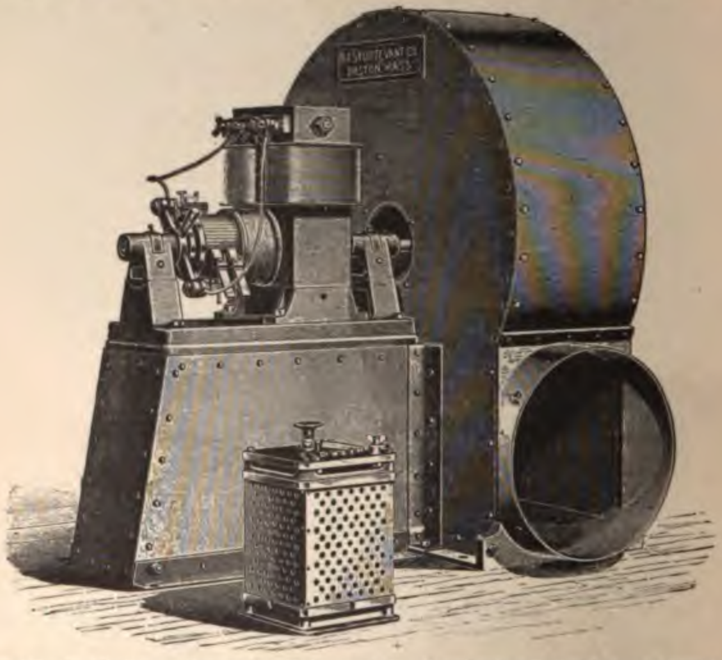

Fig. 147. Small, Direct-Connected Exhauster for Ventilating Toilet-Rooms, Chemical Hoods, etc.

As already stated, the rotation of a fan of this type sets in motion the air between the blades, which, by the action of centrifugal force, is delivered at the periphery of the wheel into the casing surrounding it. As the velocity of flow through the discharge outlet depends upon the pressure or head within the casing, and this in turn upon the velocity of the blades, it becomes necessary to examine briefly into the relations existing between these quantities.

Pressure. The pressure referred to in connection with a fan, is that in the discharge outlet, and represents the force which drives the air through the ducts and flues. The greater the pressure with a given resistance in the pipes, the greater will be the volume of air delivered; and the greater the resistance, the greater the pressure required to deliver a given quantity.

The pressure within a fan casing is caused by the air being thrown from the tips of the blades, and varies with the velocity of rotation; that is, the higher the speed of the fan, the greater will be the pressure produced. Where the dimensions of a fan and casing are properly proportioned, the velocity of air-flow through the outlet will be the same as that of the tips of the blades, and the pressure within the casing will be that corresponding to this velocity.

Table XXXIII gives the necessary speed for fans of different diameters to produce different pressures, and also the velocity of air-flow due to these pressures.

TABLE XXXIII

Fan Speeds, Pressures, and Velocities of Air-Flow

Pressure, in Ounces per Sq. Inch	Diameter of Fan Wheel, in Feet								Velocity of Flow, in Feet per Minute
	3	4	5	6	7	8	9	10	
	Revolutions per Minute								
$\frac{1}{4}$	274	206	164	137	117	103	92	82	2,585
$\frac{3}{8}$	336	252	202	168	144	126	112	101	3,165
$\frac{1}{2}$	338	291	232	194	166	146	129	116	3,653
$\frac{5}{8}$	433	325	260	217	186	163	144	130	4,084

The application of this table will be made plain by a brief discussion of *blast area.*

Blast Area. When the outlet from a fan casing is small, the air will pass out with a velocity equal to that of the tips of the blades; and the pressure within the casing will be that corresponding to the tip velocity. That is, a 3-foot fan wheel revolving at a speed of 274 revolutions per minute will produce a pressure within the fan casing of $\frac{1}{4}$ ounce per square inch, and will cause a velocity of flow through the discharge outlet of 2,585 feet per minute (see Table XXXIII).

Now, if the opening be slowly increased, while the speed of the fan remains constant, the air will continue to flow with the same velocity until a certain area of outlet is reached. If the outlet be still further increased, the pressure in the casing will begin to drop, and the velocity of outflow become less than the tip velocity. The effective area of outlet at the point when this change begins to take place, is called the ***blast area*** or ***capacity area*** of the fan. This varies somewhat with different types and makes of fans; but for the common form of blower, it is approximately $\frac{1}{3}$ of the projected area of the fan opening at the periphery—that is, $\frac{Dw}{3}$, in which D is the diameter of the fan wheel, and w its width at the periphery. It has already been stated under "General Proportions" that $W = .52\,D$, and $w = .8\,W$; so that we may write $A = \frac{D \times .8\,W}{3} = \frac{D \times .8 \times .52\,D}{3} = .14\,D^2$, in which A = the blast area, and D the diameter of the fan.

As a matter of fact, the outlet of a fan casing is always made larger than the blast area; and the result is that the pressure drops below that due to the tip velocity, and the velocity of flow through the outlet becomes less than that given in the last column of Table XXXIII for any given speed of fan.

Effective Area of Outlet. The size of discharge outlet varies somewhat for different makes; but for a large number of fans examined it was found to average about 2.22 times the blast area as computed by the above method. When air or a liquid flows through an orifice, the stream is more or less contracted, depending upon the form of the orifice.

In the case of a fan outlet, the *effective area* may be taken as about .8 of the actual area. This makes the effective area of a fan outlet equal to $.8 \times 2.22 = 1.78$ times the blast area.

Table XXXIV gives the effective areas of fans of different diameter as computed by the above method. That is, Effective area $= .14D^2 \times 1.78 = .25D^2$.

Speed. We have seen that when the discharge outlet is made larger than the blast area, the pressure within the fan casing drops below that due to the tip velocity; so that, in order to bring the pressure up to its original point, the speed of the fan must be increased above that given in Table XXXIII.

TABLE XXXIV

Effective Areas of Fans

Diameter of Fan, in Feet	Effective Area of Outlet, in Square Feet
3	2.3
4	4.0
5	6.3
6	9.1
7	12.3
8	16.0
9	20.4
10	25.2

Tests upon a fan of practically the same proportions as those previously given, show that, when the effective outlet area is made 1.78 the blast area, the speed must be increased 1.2 times in order to keep the pressure at the same point as when the outlet is equal to or less than the blast area.

Capacity. The capacity of a fan is the volume of air discharged in a given time, and is usually expressed in cubic feet per minute. It is equal to the effective area of discharge *multiplied by* the velocity of flow through it.

Example. At what speed must a 6-foot fan be run to maintain a pressure of ½ ounce, and what volume of air will be delivered per minute?

From Table XXXIII we find that a 6-foot fan must run at a speed of 194 revolutions per minute to maintain the given pressure when the outlet is equal to the blast area, or 194 × 1.2 = 233 revolutions per minute under actual conditions. The velocity of flow through the outlet at ½ ounce pressure, is 3,653 feet per minute (Table XXXIII); and the effective area of outlet of a 6-foot fan is 9.1 square feet (Table XXXIV). Therefore the volume of air delivered per minute is equal to 9.1 × 3,653 = 33,242 cubic feet.

Example. It is desired to move 52,000 cubic feet of air per minute at a pressure of ¼ ounce. What size and speed of fan will be required? Looking in Table XXXIII, we find that the velocity through the fan outlet for ¼-ounce pressure is 2,585, which calls for an outlet area of 52,000 ÷ 2,585 = 20.1 square feet. Looking in Table XXXIV, we find this corresponds very nearly to a 9-foot fan, which is the size called for. Referring again to Table XXXIII, the speed necessary to maintain the required pressure under the given conditions is found to be 92 × 1.2 = 110 revolutions per minute.

Effect of Resistance. Thus far it has been assumed that the fan was discharging into the open air against atmospheric pressure. The effect of adding a resistance by connecting it with a series of ventilating ducts, is the same as partially closing the discharge outlet. Carefully conducted tests upon this type of fan have shown that the reduction of air-flow is very nearly in proportion to the reduction of the discharge area. That is, if the outlet of the fan is closed to one-half its original area, the quantity of air discharged will be practically one-half that delivered by the fan with a free opening. The effect of attaching a fan to the ventilating flues of a building like a schoolhouse, church, or hall, where the ducts have easy bends and where the velocity of air-flow through them is not over 1,000 to 1,200 feet per minute, is about the same as reducing the outlet 20 per cent. For factories with deep heaters and smaller ducts, where the velocity runs up to 1,500 or 1,800 feet per minute, the effect is equivalent to closing the outlet at least 30 per cent, and even more in very large buildings.

For schoolhouses and similar work a fan should not be run much above the speed necessary to maintain a pressure of $\frac{3}{8}$ ounce at the outlet. Higher speeds are accompanied with greater expenditure of power, and are likely to produce a roaring noise or to cause vibration. A much lower speed does not provide sufficient pressure to give proper control of the air-distribution during strong winds. For factories, a higher pressure of $\frac{5}{8}$ to $\frac{3}{4}$ ounce is more generally employed.

Actually the pressure is increased slightly by restricting the outlet at constant speed; but this is seldom taken into account in ventilating work, as volume, speed, and power are the quantities sought.

Example. A school building requires 32,000 cubic feet of air per minute. What size and speed of fan will be required?

If the resistance of the ducts and flues is equivalent to cutting down the discharge outlet 20 per cent, we must make the computations for a fan which will discharge 32,000 ÷ .8 = 40,000 cubic feet in free air.

Looking in Table XXXIII, we find the velocity for $\frac{3}{8}$-ounce pressure to be 3,165 feet per minute; therefore the size of fan outlet must be 40,000 ÷ 3,165 = 12.6 square feet, which, from Table XXXIV, we find corresponds very nearly to a 7-foot fan.

Referring again to Table XXXIII, the required speed is found to be 144 × 1.2 = 173 revolutions per minute.

Example. A factory requires 21,000 cubic feet of air per minute for warming and ventilating. What size and speed of fan will be required?

21,000 ÷ .7 = 30,000, the volume to provide for with a fan discharging into free air. Assuming a pressure of ⅝ ounce, the velocity will be 4,084 feet per minute, from which the area of outlet is found to be 30,000 ÷ 4,084 = 7.3 square feet. This, we find, does not correspond to any of the sizes given in Table XXXIV. As standard fans are not usually made in half-sizes above 5 feet, we shall use a 5-foot fan and run it at a higher speed.

A 5-foot fan has an outlet area of 6.3 square feet, and at ⅝-ounce pressure it would deliver 6.3 × 4,084 = 25,729 cubic feet of air per minute, at a speed of 260 × 1.2 = 312 revolutions per minute. The volume of air delivered by a fan varies approximately as the speed; so, in order to bring the volume up to the required 30,000, the speed must be increased by the ratio 30,000 ÷ 25,729 = 1.16, making the final speed 312 × 1.16 = 362 revolutions per minute. In the same way, a 6-foot fan could have been used and run at a proportionally lower speed.

Power Required. The work done by a fan in moving air is represented by the pressure exerted, *multiplied by* the distance through which it acts.

Table XXXV gives the horse-power required for moving the air which will flow through each square foot of the effective outlet area, under different pressures.

This table gives only the power necessary for *moving* the air, and does not take into consideration the friction of the air in passing through the fan, nor that of the fan itself.

The efficiency of a fan varies with the speed, the size of outlet, and the pressure against which the fan is working. Under favorable conditions, with properly proportioned fans, we may count on an efficiency of about .35.

Example. What horse-power will be required to drive an 8-foot fan at such a speed as to maintain a pressure of ½ ounce?

An 8-foot fan has an outlet area of 16 square feet (Table XXXIV); and from Table XXXV we find that .5 horse-power is required to move the air which will flow through each square foot of outlet under

TABLE XXXV

Power Required for Moving Air under Different Pressures

PRESSURE IN OUNCES PER SQUARE INCH	HORSE-POWER FOR MOVING AIR WHICH WILL FLOW THROUGH EACH SQUARE FOOT OF EFFECTIVE OUTLET AREA
$\frac{1}{4}$	.18
$\frac{3}{8}$	.33
$\frac{1}{2}$	.50
$\frac{5}{8}$	.70

$\frac{1}{2}$-ounce pressure. Therefore the power required to move the air alone is $16 \times .5 = 8$, and the total horse-power is $8 \div .35 = 23$.

Effect of Resistance. In the above case, it is assumed that the fan is discharging into free air. If a resistance is added, the effect is the same as partially closing the outlet, and the volume of air moved and the horse-power required are both reduced in very nearly the same proportion. This reduction, as already stated, may be taken as 20 per cent for schoolhouse and similar work, and 30 per cent for factories.

For example, if the fan just considered was to be used for ventilating a schoolhouse, delivering air under a pressure of $\frac{1}{2}$ ounce, the necessary horse-power would be only $23 \times .8 = 18.4$. If used for a factory, delivering air under a pressure of $\frac{5}{8}$ ounce, the required horse-power would be $\frac{16 \times .7}{.35} \times .7 = 22.3$.

General Rules. The methods above described may be briefly expressed as follows:

CAPACITY—$Q = A \times v \times F$, in which

Q = Cubic feet of air per minute;

A = Effective area of fan outlet (Table XXXIV);

v = Velocity of flow through outlet;

$$\begin{cases} 3{,}165 \ (\tfrac{3}{8}\text{-ounce pressure) for schoolhouses, etc.;} \\ 4{,}084 \ (\tfrac{5}{8}\text{-ounce pressure) for factories;} \end{cases}$$

$$F = \begin{cases} .8 \text{ for schoolhouses, etc.;} \\ .7 \text{ for factories.} \end{cases}$$

SPEED—Take the speed from Table XXXIII, corresponding to the given pressure and size of fan, and multiply by 1.2.

HORSE-POWER—H.P. = $\frac{A \times p \times F}{.35}$, in which

H.P. = Horse-power;

A = Effective area of fan outlet;

p = Horse-power to move air which will flow through 1 square foot of fan outlet under given pressure (Table XXXV);

$$= \begin{cases} .33 \text{ for schoolhouses, etc.;} \\ .7 \text{ for factories.} \end{cases}$$

$$F = \begin{cases} .8 \text{ for schoolhouses, etc.;} \\ .7 \text{ for factories.} \end{cases}$$

EXAMPLES

1. A schoolhouse requires an air-supply of 30,000 cubic feet per minute. What will be the required size of fan, its speed, and the H. P. of engine to drive it?

$$\text{Ans.} \begin{cases} \text{7 ft. in diameter.} \\ \text{173 r. p. m.} \\ \text{9 H. P.} \end{cases}$$

2. What will be the size and speed of fan, and horse-power of engine, to heat and ventilate a factory requiring 1,080,000 cubic feet of air per hour?

$$\text{Ans.} \begin{cases} \text{6 ft. in diameter.} \\ \text{260 r. p. m.} \\ \text{8.8 H. P.} \end{cases}$$

General Relations. The following general relations between the volume, pressure, and power will often be found useful in deciding upon the size of a fan:

(1) The volume of air delivered varies *directly* as the speed of the fan; that is, doubling the number of revolutions doubles the volume of air delivered.

(2) The pressure varies as the *square* of the speed. For example, if the speed is doubled, the pressure is increased $2 \times 2 = 4$ times; etc.

(3) The power required to run the fan varies as the *cube* of the speed. Thus, if the speed is doubled, the power required is increased $2 \times 2 \times 2 = 8$ times; etc.

The value of a knowledge of these relations may be illustrated by the following example:

Suppose for any reason it were desired to double the volume of air delivered by a certain fan. At first thought we might decide to use the same fan and run it twice as fast; but when we come to consider the power required, we should find that this would have to be increased 8 times, and it would probably be much cheaper in the long run to put in a larger fan and run it at lower speed.

Disc or Propeller Fans. When air is to be moved against a very slight resistance, as in the case of exhaust ventilation, the disc or propeller type of wheel may be used. This is shown in different forms in Figs. 149 and 150. This type of fan is light in construction, requires but little power at low speeds, and is easily erected. It may be conveniently placed in the attic or upper story of a building, where it may be driven either by a direct- or belt-connected electric motor. Fig. 148 shows a fan equipped with a direct-connected motor, and Fig. 151 the general arrangement when a belted motor is used. These fans are largely used for the ventilation of toilet and smoking rooms, restaurants, etc., and are usually mounted in a wall opening, as shown in Fig. 151. A damper should always be provided for shutting off the opening when the fan is not in use. The fans shown in Figs. 149 and 150 are provided with pulleys for belt connection.

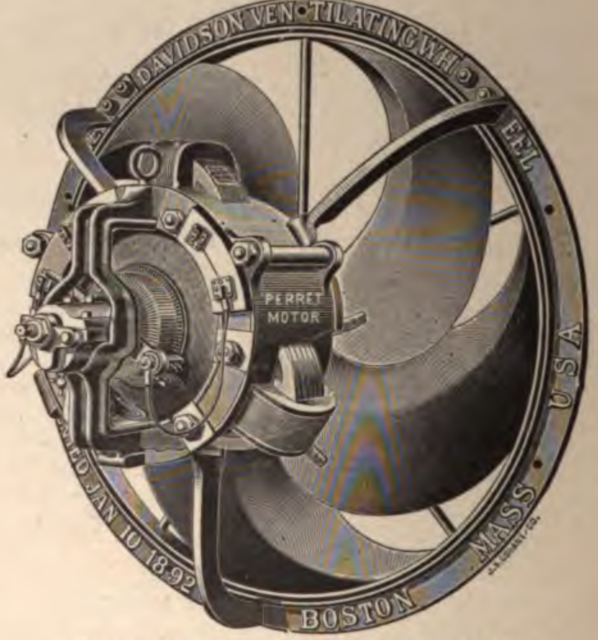

Fig. 148. Propeller Fan Direct-Connected to Motor.

Fans of this kind are often connected with the main vent flues of large buildings, such as schools, halls, churches, theaters, etc., and are especially adapted for use in connection with gravity heating systems. They are usually run by electric motors, and as a rule are placed in positions where an engine could not be connected, and also in buildings where steam pressure is not available.

Capacity of Disc Fans. The capacity of a disc fan varies greatly with the type and the conditions under which it operates. The rated capacities usually given in catalogues are for fans revolving in free air—that is, mounted in an opening without being connected with ducts or subjected to other frictional resistance.

As the capacity and necessary power are so dependent upon the resistance to be overcome, it is difficult to give definite rules for determining them. The following data, based upon actual tests, apply to fans working against a resistance such as would be produced by connecting with a system of ducts of medium length through which the air was drawn at a velocity not greater than 600 or 800 feet per minute. Under these conditions, a good type of fan will propel the air in a direction parallel to the shaft a distance equal to about .7 of its diameter at each revolution; and from this we have the equation:

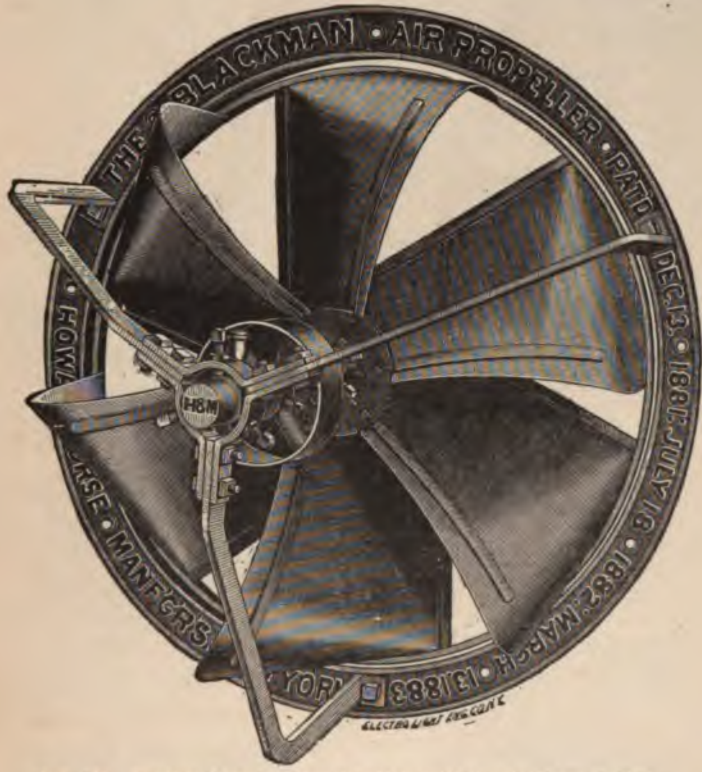
THE BLACKMAN · AIR PROPELLER · PAT'D · DEC.13.1881 · JULY 18.1882 · MARCH 13.1883
YORK
MORSE · MANFGRS
H&M

Fig. 149. Another Form of Propeller Fan, with Special Type of Blade.

$$Q = .7\,D \times R \times A,$$

in which

Q = Cubic feet of air discharged per minute;
D = Diameter of fan, in feet;
R = Revolutions per minute;
A = Area of fan, in square feet.

In order to obtain the best results, the linear velocity of air-flow through the fan should range from 800 to 1,200 feet per minute.

Table XXXVI gives the revolutions per minute for fans of different diameter to produce a linear velocity of 1,000 feet, the volume delivered at this speed, and the horse-power required.

The horse-power is computed by allowing .14 H. P. for each 1,000 cubic feet of air moved, when the velocity through the fan is 800 feet per minute; .16 H. P. for 1,000 feet velocity; and .18 H. P. for 1,200 feet velocity. These factors are empirical, and based on tests.

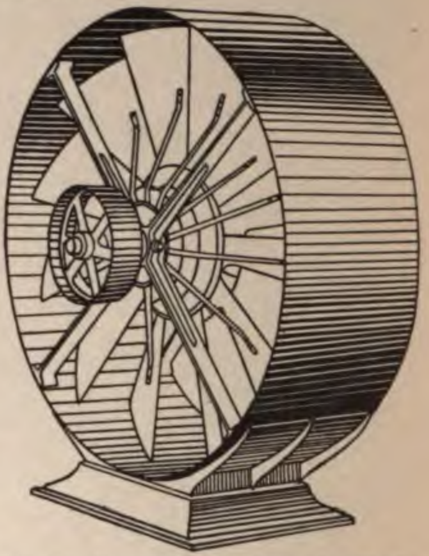

Fig. 150. Propeller Fan with Wheel on Shaft for Belt Connection.

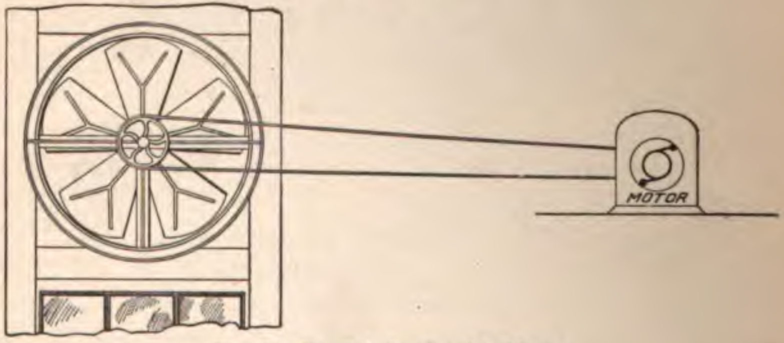

Fig. 151. Fan Belt-Connected to Motor.

Example. Assuming a velocity of 800 feet per minute through a 4-foot fan, what volume will be delivered per minute, and what speed and horse-power will be required?

TABLE XXXVI

Disc Fans, their Capacity, Speed, etc.

DIA. OF FAN, IN INCHES	REV. PER MIN.	CUBIC FEET OF AIR MOVED	HORSE-POWER REQUIRED
18	952	1,700	.27
24	716	3,100	.50
30	572	4,900	.78
36	476	7,100	1.2
42	408	9,400	1.5
48	343	12,000	1.9
54	317	15,800	2.5
60	286	19,400	3.1
72	238	28,300	4.5

The area of a 4-foot fan is 12.5 square feet; and at 800 velocity the volume would be 12.5 × 800 = 10,000 cubic feet. Next solve for the speed by the equation $Q = .7D \times R \times A$, which, when transposed, takes the form

$$R = \frac{Q}{.7\,D \times A}.$$

Substituting the known quantities, we have:

$$R = \frac{10,000}{.7 \times 4 \times 12.5} = 286.$$

The horse-power is 10 × .14 = 1.4.

Fan Engines. A simple, quiet-running engine is desirable for use in connection with a fan or blower. The engine may be either horizontal or vertical; and for schoolhouse and similar work, should be provided with a large cylinder, so that the required power may be developed without carrying a boiler pressure much above 30 pounds. In some cases, cylinders of such size are used that a boiler pressure of 12 or 15 pounds is sufficient. The quantity of steam which an engine consumes is of minor importance, as the exhaust can be turned into the coils and used for heating purposes. If space allows, the engine should always be belted to the fan. Where it is direct-connected, as in Fig. 144, there is likely to be trouble from noise, as any slight looseness or pounding in the engine will be communicated to the air-ducts, and the sound will be carried to the rooms above. Figs. 152 and 153 show common forms of fan engines. The latter is especially adapted to this purpose, as all bearings are enclosed

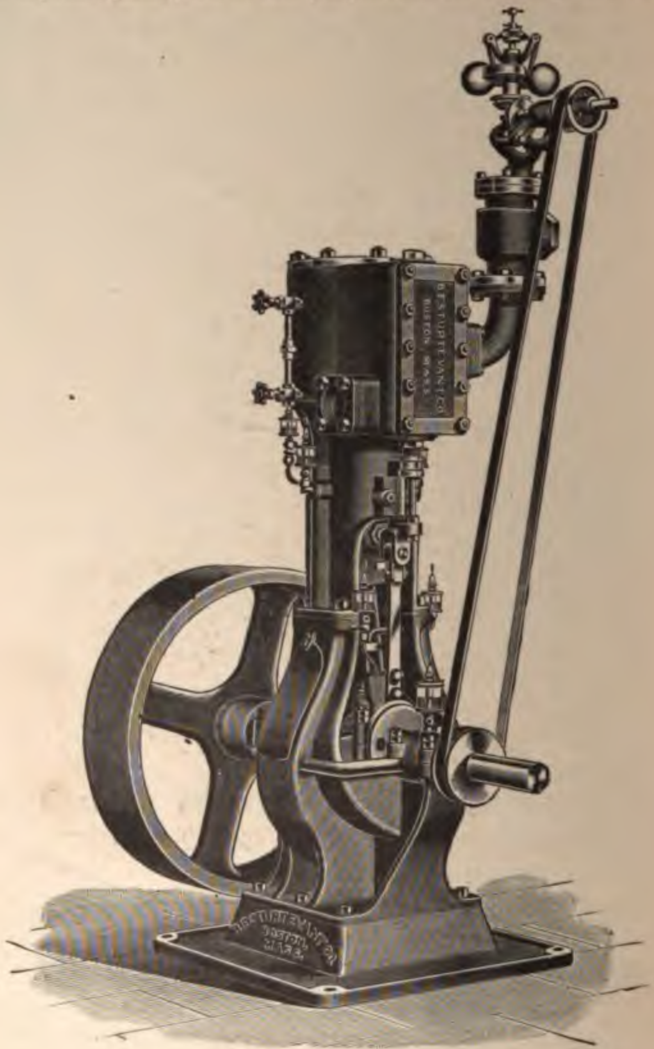

Fig. 152. A Common Form of Fan Engine.

and protected from dust and grit. A horizontal engine for fan use is shown in Fig. 154.

In case an engine is belted, the distance between the shafts of the fan and engine should not in general be much less than 10 feet for fans up to 7 or 8 feet in diameter, and 12 feet for those of larger size. When possible, the tight or driving side of the belt should be at the bottom, so that the loose side, coming on top, will tend to wrap around the pulleys and so increase the arc of contact.

Motors. Electric motors are especially adapted for use in connection with fans. This method of driving is more expensive than by the use of an engine, especially if electricity must be purchased from outside parties; but if the building contains its own power plant, so that the exhaust steam can be utilized for heating, the convenience and simplicity of motor-driven fans often more than offset the additional cost of operation.

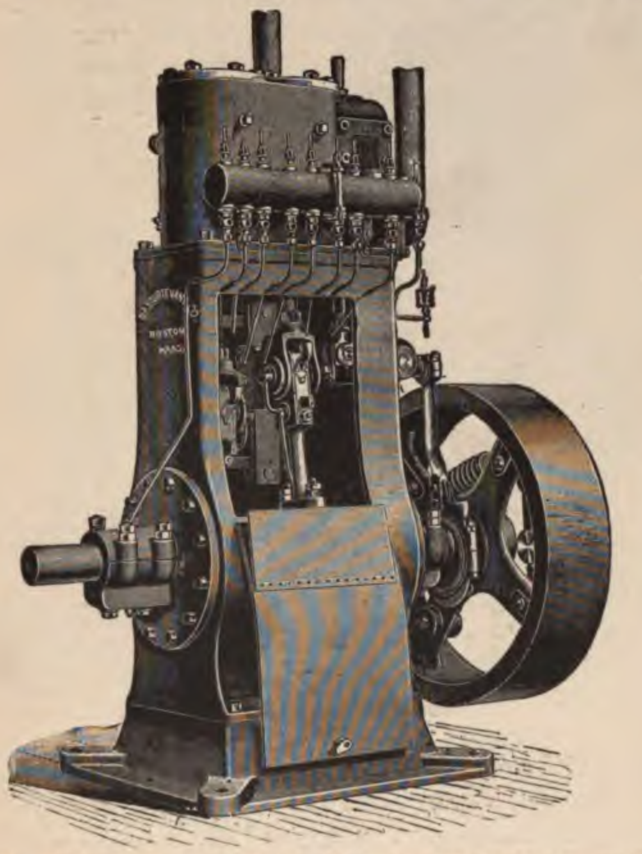

Fig. 153. Another Form of Fan Engine, with Bearings Enclosed to Protect Them from Dust and Grit.

Direct-connected motors are always preferable to belted, if a direct current is available, on account of greater quietness of action. This is due both to the slower speed of the motor and to the absence of belts.

Sufficient speed regulation can be obtained with direct-connected machines, without excessive waste of energy, by the use of a rheostat.

If a direct current is not available, and an alternating current must be used, the advantages of electric driving are greatly reduced, as high-speed motors with belts must be employed, and, furthermore, satisfactory speed regulation is not easily attainable.

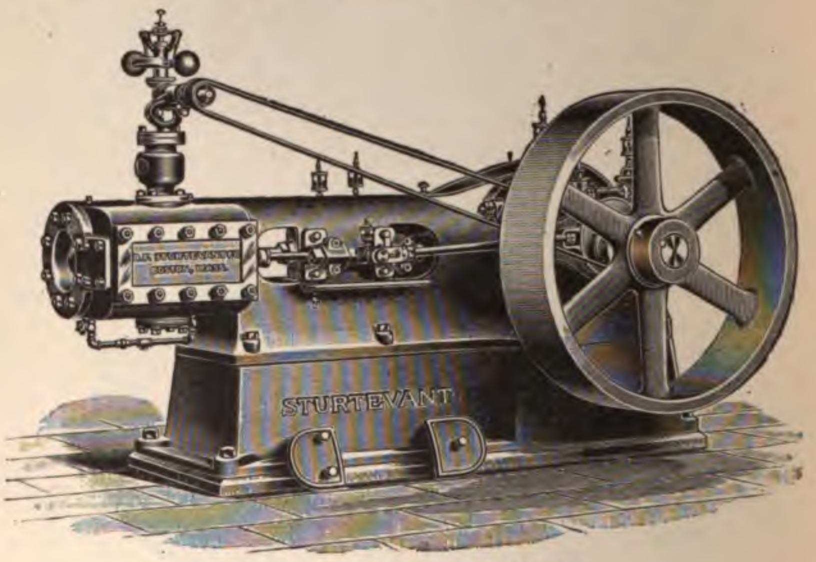

Fig. 154. Horizontal Engine for Fan Use.

Area of Ducts and Flues. With the blower type of fan, the size of the main ducts may be based on a velocity of 1,200 to 1,500 feet per minute; the branches, on a velocity of 1,000 to 1,200 feet per minute, and as low as 600 to 800 feet when the pipes are small. Flue velocities of 500 to 700 feet per minute may be used, although the lower velocity is preferable. The size of the inlet register should be such that the velocity of the entering air will not exceed about 300 feet per minute. The velocity between the inlet windows and the fan or heater should not exceed about 800 feet.

The air-ducts and flues are usually made of galvanized iron, the ducts being run at the basement ceiling. No. 20 and No. 22 iron is used for the larger sizes, and No. 24 to No. 28 for the smaller.

Regulating dampers should be placed in the branches leading to each flue, for increasing or reducing the air-supply to the different rooms. Adjustable deflectors are often placed at the fork of a pipe for the same purpose. One of these is shown in Fig. 155.

Fig. 156 illustrates a common arrangement of fan and heater where the type of heater shown in Fig. 138 is used; and Fig. 157 is a self-contained apparatus in which the heater is inclosed in a steel casing.

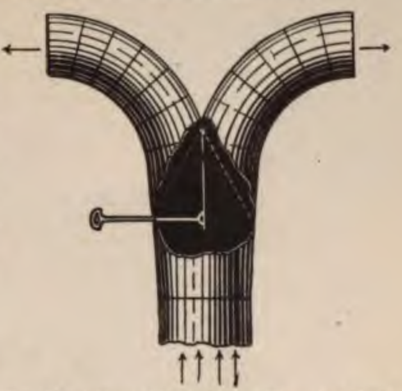

Fig. 155. Adjustable Deflector Placed at Fork of Pipe to Regulate Air-Supply.

Factory Heating. The application of forced blast for the warming of factories and shops, is shown in Figs. 158 and 159. The proportional heating surface in this case is generally expressed in the number of cubic feet in the building for each linear foot of 1-inch steam pipe in the heater. On this basis, in factory practice, with all of the air taken from out of doors, there are generally allowed from 100 to 150 cubic feet of space per foot of pipe, according as exhaust or live steam is used, live steam in this case indicating steam of about 80 pounds pressure. If practically all the air is returned from the

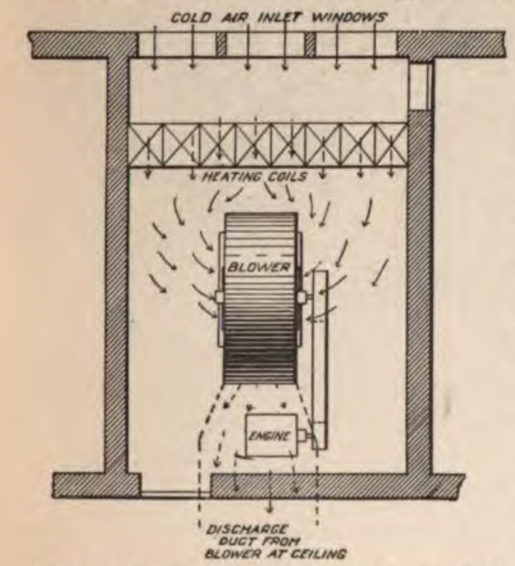

Fig. 156. Common Arrangement of Fan with Heater of Type Shown in Fig. 138.

buildings to the heater, these figures may be raised to about 140 as a minimum, and possibly 200 as a maximum, per foot of pipe. The heaters in Table XXXI may be changed to linear feet of 1 inch pipe by multiplying the numbers in column three (square feet of surface) by three.

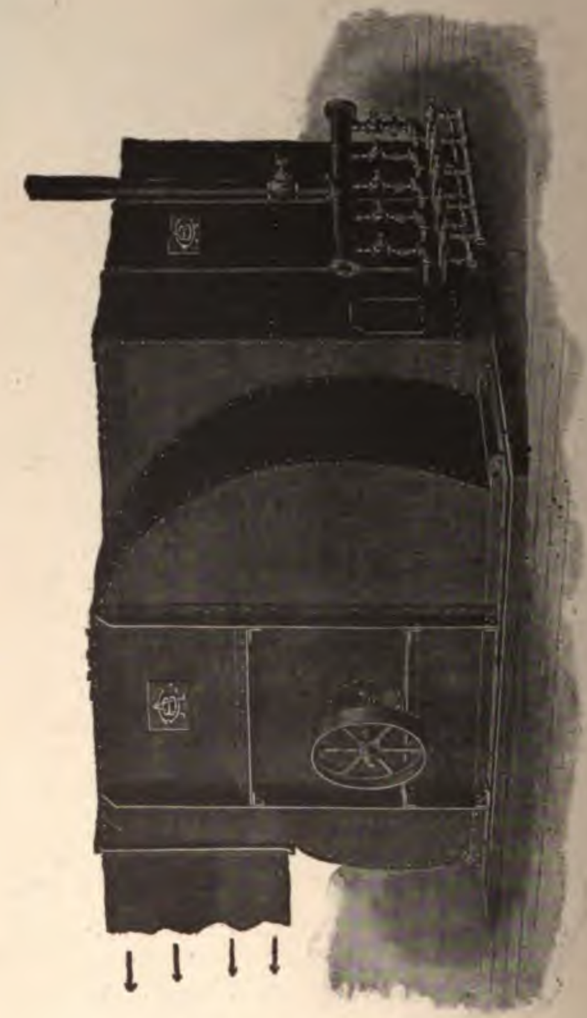

Fig. 157. Self Contained Heater and Blower in Steel Casing.

EXAMPLES FOR PRACTICE

1. A machine shop 100 feet long by 50 feet wide and having 3 stories, each 10 feet high, is to be warmed by forced blast, using exhaust steam in the heater. The air is to be returned to the heater from the building, and the whole amount contained in the building is to pass through the heater every 15 minutes. What size of blower

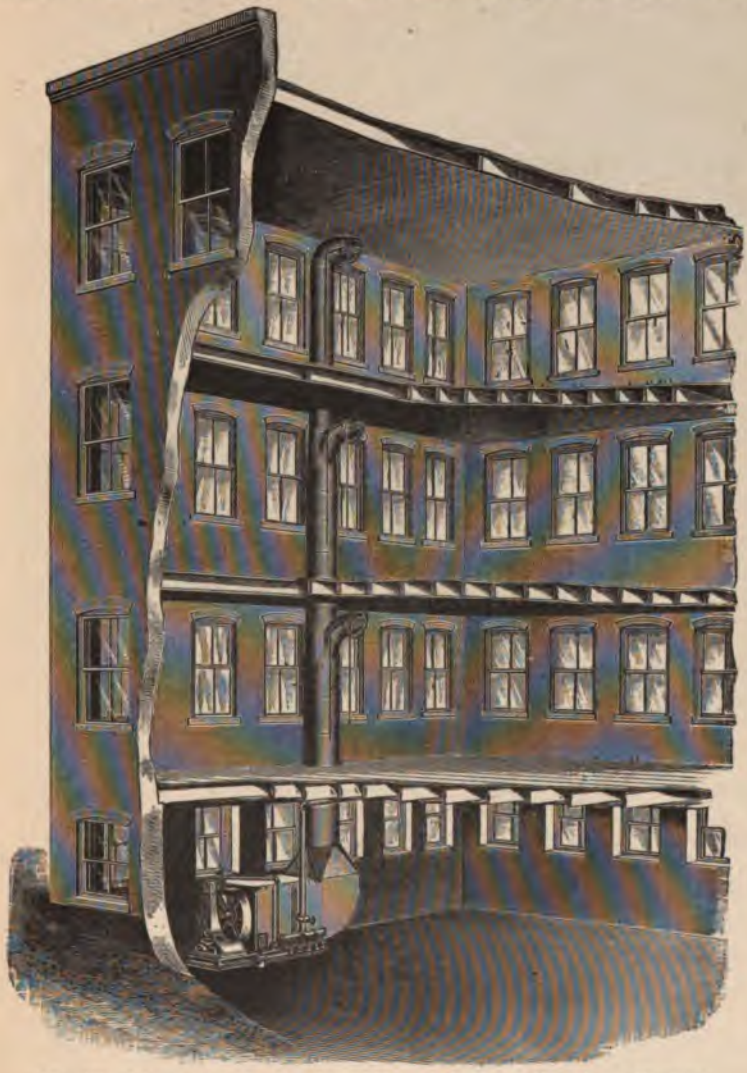

Fig. 158. Illustrating Application of Forced Blast for Warming a Factory.

will be required, and what will be the H. P. of the engine required to run it? How many linear feet of 1-inch pipe should the heater contain?

Ans. 4-foot blower.
6 H. P. engine.
1,071 feet of pipe.

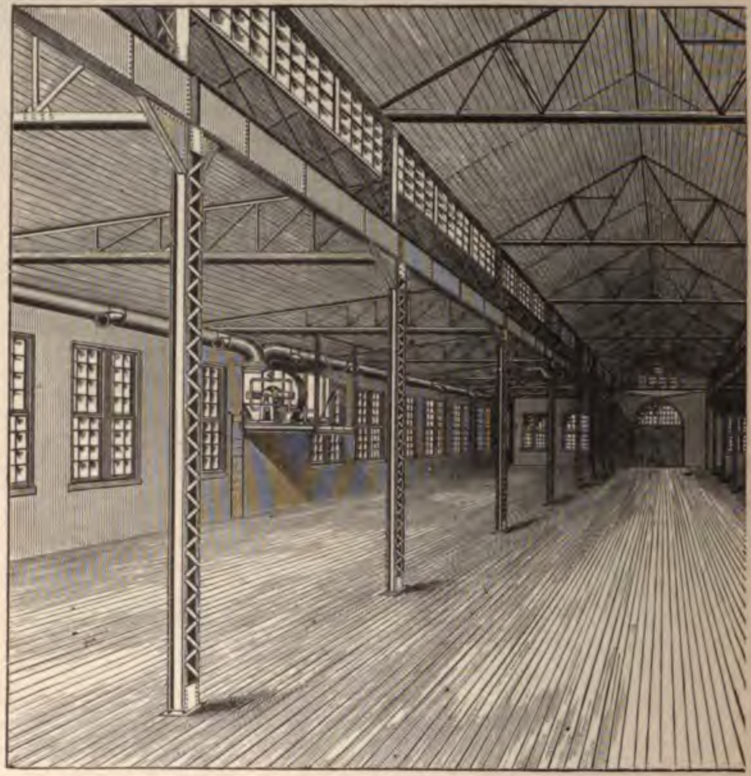

Fig. 159. Centrifugal Blower Producing Forced Blast for Heating a Shop.

2. Find the size of blower, engine, and heater for a factory 200 feet long, 60 feet wide, and having 4 stories, each 10 feet high, using live steam at 80 pounds pressure in the heater, and changing the air every 20 minutes by taking in cold air from out of doors.

Ans. 6-foot blower.
13 H. P. engine.
3,200 feet of pipe.

In using this method of computation, judgment must be employed, which can come only from experience. The figures given are for average conditions of construction and exposure.

Double-Duct System. The varying exposures of the rooms of a school or other building similarly occupied, require that more heat shall be supplied to some than to others. Rooms that are on the south side of the building and exposed to the sun, may perhaps be kept perfectly comfortable with a supply of heat that will maintain a temperature of only 50 or 60 degrees in rooms on the opposite side of the building which are exposed to high winds and shut off from the warmth of the sun.

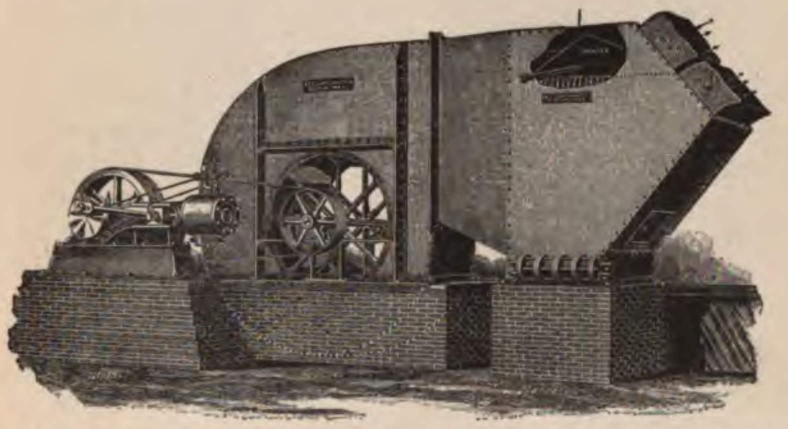

Fig. 160. Hot-Blast Apparatus with Double Duct for Supplying Air at Different Temperatures to Different Parts of a Building.

With a constant and equal air-supply to each room, it is evident that the temperature must be directly proportional to the cooling surfaces and exposure, and that no building of this character can be properly heated and ventilated if the temperature cannot be varied without affecting the air-supply.

There are two methods of overcoming this difficulty:

The older arrangement consists in heating the air by means of a primary coil at or near the fan, to about 60 degrees, or to the minimum temperature required within the building. From the coil it passes to the bases of the various flues, and is there still further heated as required, by secondary or supplementary heaters placed at the base of each flue.

With the second and more recent method, a single heater is employed, and all the air is heated to the maximum required to maintain the desired temperature in the most exposed rooms, while the temperature of the other rooms is regulated by mixing with the hot air a sufficient volume of cold air at the bases of the different flues. This result is best accomplished by designing a hot-blast apparatus so that the air shall be forced, rather than drawn through the heater, and by providing a by-pass through which it may be discharged without passing across the heated pipes.

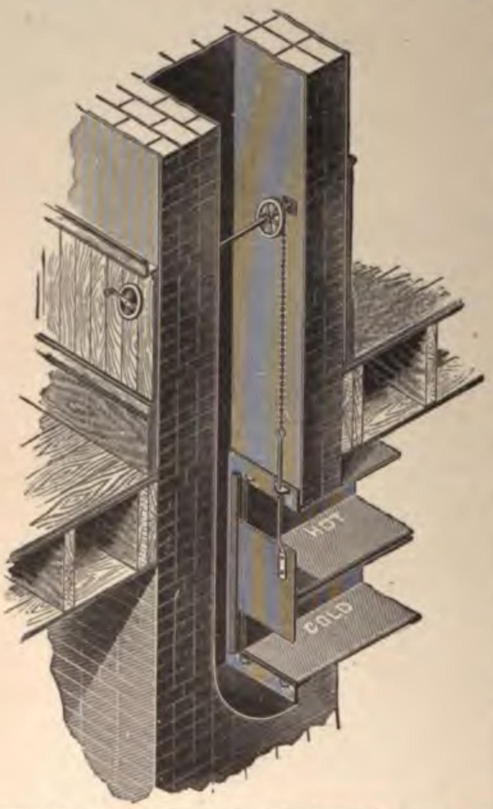

Fig. 161. Mixing Damper for Regulating Temperature of Air Supplied by Double-Duct System.

The passage for the cool air is usually above and separate from the heater pipes, as shown in Fig. 160. Extending from the apparatus is a double system of ducts, usually of galvanized iron, suspended from the ceiling. At the base of each flue is placed a mixing damper, which is controlled by a chain from the room above, and so designed as to admit either a full volume of hot air, a full volume of cool or tempered air, or to mix them in any desired proportion without affecting the resulting total volume delivered to the room. A damper of this form is shown in Fig. 161.

Fig. 162 shows an arrangement of disc fan and heater where the air is first drawn through a tempering coil, then a portion of it forced through a second heater and into the warm-air pipes, while the remainder is by-passed under the heater into the cold-air pipes. Mixing dampers are placed at the bases of the flues as already described, to regulate the temperature in different rooms.

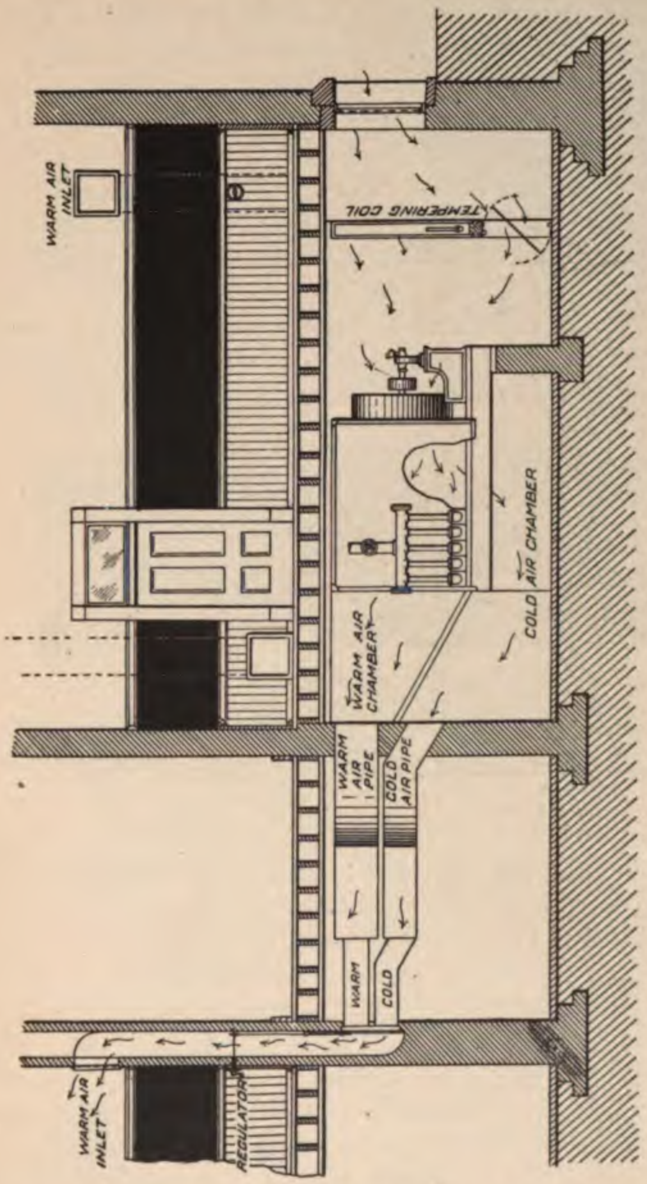

Fig. 162. Warming System Combining Tempering Coil, Disc Fan, Second Heater, and Double Ducts.

ELECTRIC HEATING

Unless electricity is produced at a very low cost, it is not commercially practicable for heating residences or large buildings. The electric heater, however, has quite a wide field of application in heating small offices, bathrooms, electric cars, etc. It is a convenient method of warming rooms on cold mornings in late spring and early fall, when furnace or steam heat is not at hand. It has the special advantage of being instantly available, and the amount of heat can be regulated at will. The heaters are perfectly clean, do not vitiate the air, and are portable.

Electric Heat and Energy. The commercial unit for electricity is one watt for one hour, and is equal to 3.41 B. T. U. Electricity is usually sold on the basis of 1,000 watt-hours (called *Kilowatt-hours*), which is equivalent to 3,410 B. T. U. A watt is the product obtained by multiplying a current of 1 ampere by an electromotive force of 1 volt.

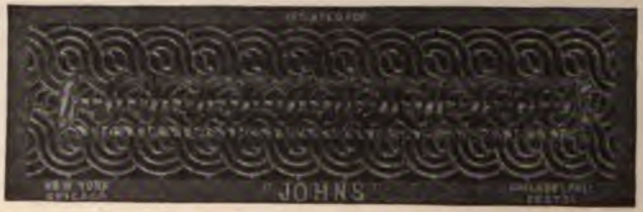

Fig. 163. Electric Car-Heater.

From the above we see that the B. T. U. required per hour for warming, divided by 3,410, will give the kilowatt-hours necessary for supplying the required amount of heat.

Construction of Electric Heaters. Heat is obtained from the electric current by placing a greater or less resistance in its path. Various forms of heaters have been employed. Some of the simplest consist merely of coils or loops of iron wire, arranged in parallel rows, so that the current can be passed through as many coils as are needed to provide the required amount of heat. In other forms, the heating material is surrounded with fire-clay, enamel, or asbestos, and in some cases the material itself has been such as to give considerable resistance to the current. A form of electric car-heater is shown in Fig. 163. Forms of radiators are shown in Figs. 164 and 165.

Calculation of Electric Heaters. The formula for the calculation of electric heaters is

$$H = I^2 R t \times .24,$$

in which

H = Heat, in calories;
I = Current, in amperes;
R = Resistance, in ohms;
t = Time, in seconds.

Fig. 164. Electric Radiator.

Examples. What resistance must an electric heater have, to give off 6,000 B. T. U. per hour, with a current of 20 amperes?

We have learned that 1 B. T. U. = 252 calories; so, in the present case, 6,000 × 252 = 1,512,000 calories must be provided.

Substituting the known values in the formula, we have

$$1{,}512{,}000 = 20^2 \times R \times 3{,}600 \times .24,$$

from which

$$R = \frac{1{,}512{,}000}{345{,}600} = 4.37 \text{ ohms}.$$

A heater having a resistance of 3 ohms is to supply 3,000 B. T. U. per hour. What current will be required?

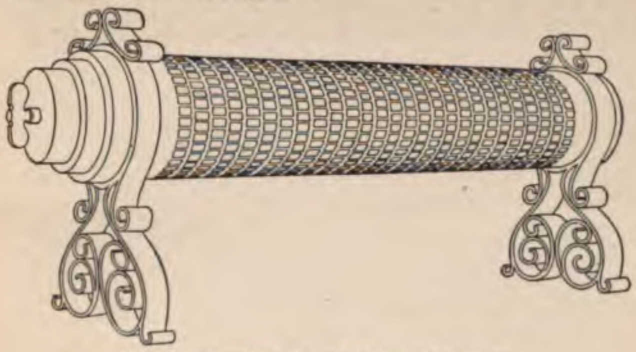

Fig. 165. Another Form of Electric Radiator.

3,000 × 252 = 756,000 calories. Substituting the known values in the formula, and solving for I, we have

$$756{,}000 = I^2 \times 3 \times 3{,}600 \times .24,$$

from which

$$I = \sqrt{291.6} = 17 + \text{amperes}.$$

Connections for Electric Heaters. The method of wiring for electric heaters is essentially the same as for lights which require the same amount of current. A constant electromotive force or voltage is maintained in the main wire leading to the heaters. A much less voltage is carried on the return wire, and the current in passing through the heater from the main to the return, drops in voltage or pressure. This drop provides the energy which is transformed into heat.

The principle of electric heating is much the same as that involved in the non-gravity return system of steam heating. In that system, the pressure on the main steam pipes is that of the boiler, while that on the return is much less, the reduction in pressure occurring in the passage of the steam through the radiators; the water of condensation is received into a tank, and returned to the boiler by a pump.

In a system of electric heating, the main wires must be sufficiently large to prevent a sensible reduction in voltage or pressure between the generator and the heater, so that the pressure in them shall be substantially that in the generator. The pressure or voltage in the main return wire is also constant, but very low, and the generator has an office similar to that of the steam pump in the system just described—that is, of raising the pressure of the return current up to that in the main. The power supplied to the generator can be considered the same as the boiler in the first case. All the current which passes from the main to the return must flow through the heater, and in so doing its pressure or voltage falls from that of the main to that of the return.

From the generator shown in Fig. 166, main and return wires are run the same as in a two-pipe system of steam heating, and these are proportioned to carry the required current without sensible drop or loss of pressure. Between these wires are placed the various heaters, which are arranged so that when electric connection is made they draw the current from the main and discharge it into the return wire. Connections are made and broken by switches, which take the place of valves on steam radiators.

Cost of Electric Heating. The expense of electric heating must in every case be great, unless the electricity can be supplied at an exceedingly low cost. Estimated on the basis of present practice, the average transformation into electricity does not account for more than 4 per cent of the energy in the fuel which is burned in the furnace. Although under best conditions 15 per cent has been realized, it would not be safe to assume that in ordinary practice more than 5 per cent could be transformed into electrical energy. In heating with steam, hot water, or hot air, the average amount utilized will probably be about 60 per cent, so that the expense of electrical heating is approximately from 12 to 15 times greater than by these methods.

TEMPERATURE REGULATORS

The principal systems of automatic temperature control now in use, consist of three essential features; *First*, an air-compressor, reservoir, and distributing pipes; *second*, thermostats, which are placed in the rooms to be regulated; and *third*, special diaphragm or pneumatic valves at the radiators.

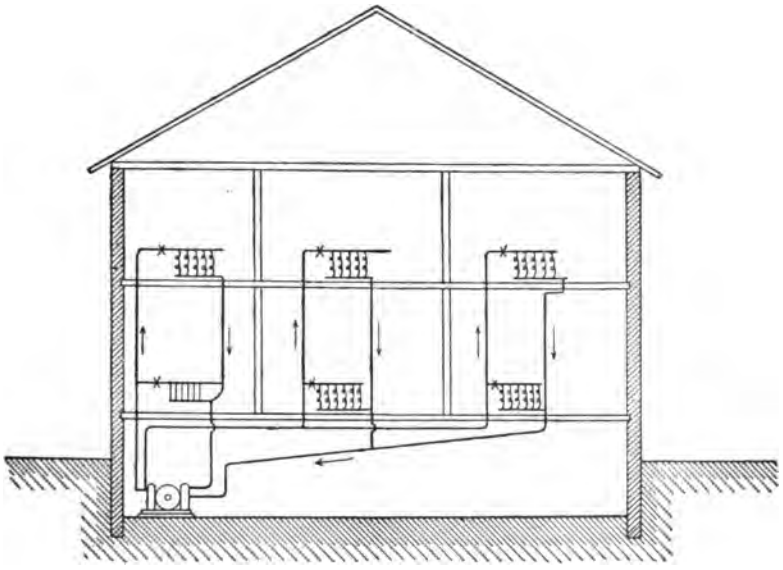

Fig. 166. General System of Wiring a House for Electric Heating.

The *air-compressor* is usually operated by water-pressure in small plants and by steam in larger ones; electricity is used in some cases. Fig. 167 shows a form of water compressor. It is similar in principle to a direct-acting steam pump, in which water under pressure takes the place of steam. A piston in the upper cylinder compresses the air, which is stored in a reservoir provided for the purpose. When the pressure in the reservoir drops below a certain point, the compressor is started automatically, and continues to operate until the pressure is brought up to its working standard.

A *thermostat* is simply a mechanism for opening and closing one or more small valves, and is actuated by changes in the temperature of the air in which it is placed. Fig. 168 shows a thermostat in which the valves are operated by the expansion and contraction of the metal strip *E*. The degree of temperature at which it acts may be adjusted by throwing the pointer at the bottom one way or the other. Fig. 169 shows the same thermostat with its ornamental

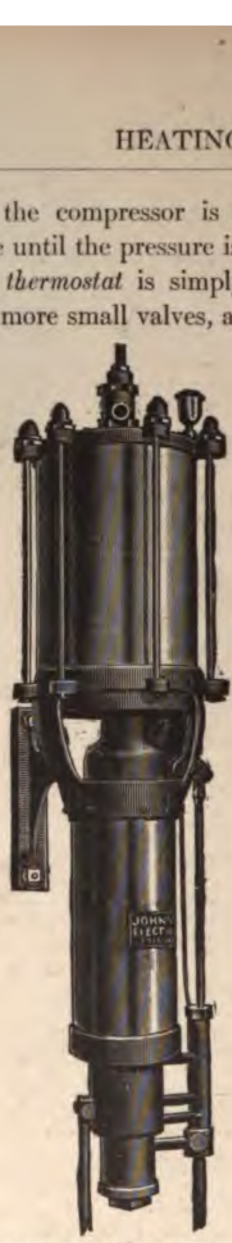

Fig. 167. Air-Compressor Operated by Water-Pressure, Automatically Controlled, and Operating to Regulate Temperature by Controlling Radiator Valves.

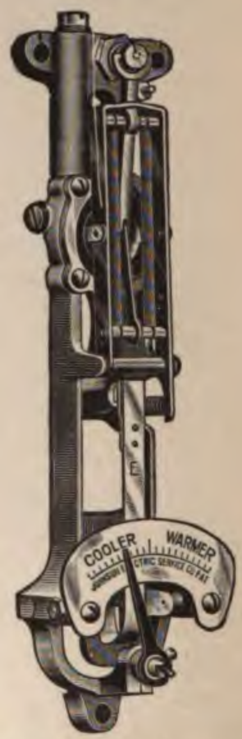

Fig. 168. Thermostat Controlling Valves on Radiators, and Operating through Expansion or Contraction of Metal Strip *E*.

casing in place. The thermostat shown in Fig. 170 operates on a somewhat different principle. It consists of a vessel separated into two chambers by a metal diaphragm. One of these chambers is partially filled with a liquid which will boil at a temperature below that desired in the room. The vapor of the liquid produces considerable pressure at the normal temperature of the room, and a slight increase of heat crowds the diaphragm over and operates the small valves in a manner similar to that of the metal strip in the case just described.

The general form of a *diaphragm valve* is shown in Fig. 171. These replace the usual hand-valves at the radiators. They are similar in construction to the ordinary globe or angle valve, except that the stem slides up and down instead of being threaded and running in a nut. The top of the stem connects with a flat plate, which rests against a rubber diaphragm. The valve is held open by a spring, as shown, and is closed by admitting compressed air to the space above the diaphragm.

In connecting up the system, small concealed pipes are carried from the air-reservoir to the thermostat, which is placed upon an inside wall of the room, and from there to the diaphragm valve at the radiator. When the temperature of the room reaches the maximum point for which the thermostat is set, its action opens a small valve and admits air-pressure to the diaphragm, thus closing off the

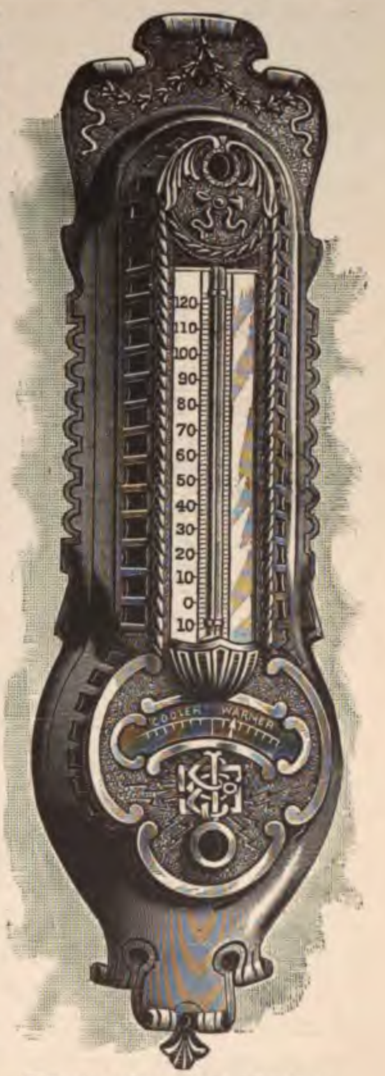

Fig. 169. Thermostat of Fig. 168 in Ornamental Casing.

steam from the radiator. When the temperature falls, the thermostat acts in the opposite manner, and shuts off the air-pressure from the diaphragm valve, at the same time opening a small exhaust which allows the air above the diaphragm to escape. The pressure being removed, the valve opens and again admits steam to the radiator.

Diaphragm Motors. Dampers are operated pneumatically in a similar manner to steam valves. A *diaphragm motor*, so called, is acted upon by the air-pressure; and this lifts a lever which is properly connected to the damper by means of chains or levers, thus securing the desired movement.

Dampers. When mixing dampers are operated pneumatically, a specially designed thermostat for giving a graduated movement to the damper should be used. By this arrangement the damper is held in such a position at all times as to admit the proper proportions of hot and cold or tempered air for producing the desired temperature in the room with which it is connected.

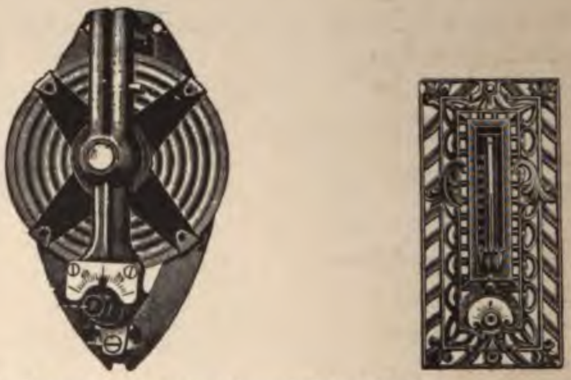

Fig. 170. Thermostat Operating through Expansion or Contraction of the Vapor of a Volatile Liquid.

Large dampers which are to be operated pneumatically, should be made up in sections or louvres. Dampers constructed in this manner are handled much more easily than when made in a single piece.

It often happens, in large plants, that there are valves and dampers in places which are not easily reached for hand manipulation. These may be provided with diaphragms and connected with the air-pressure system for operation by hand-switches or cocks conveniently located at some central point in the basement or boiler room.

Telethermometer. This is a device for indicating on a dial at some central point the temperature of various rooms or ducts in different parts of a building. A special *transmitter* is placed in each of the rooms and electrically connected with a central switchboard. Then, by means of suitable switches, any room may be thrown in circuit with the *recorder*, and the temperature existing in the room at that time read from the dial.

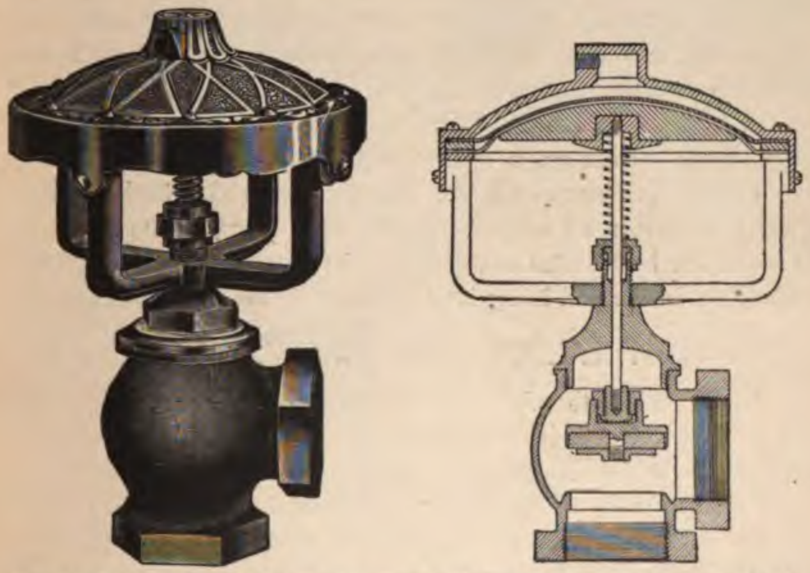

Fig. 171. Exterior View, and Section Showing Interior Mechanism of Diaphragm Valve.

Humidostat. The *humidostat* is a device to be placed in one or more rooms of a building for maintaining an even percentage of moisture in the air. The apparatus consists of two essential parts—the *humidostat* and the *humidifier*. The former corresponds to the thermostat in a system of temperature control, and operates a pneumatic valve or other mechanism connected with the humidifier when the percentage of moisture rises above or falls below certain limits. The operating medium is compressed air, the same as for temperature control; and the two devices are usually connected with the same pressure system.

The normal moisture of a room is 70 per cent, and should never exceed that. In cold weather it will be necessary to reduce the amount of moisture somewhat, owing to the "sweating" of walls and windows.

The method of moistening the air will depend somewhat upon circumstances. If the air for ventilation is delivered to the rooms at a temperature not exceeding 70 degrees, the humidifier is best placed in the main air-duct. If the air enters at a higher temperature, the humidifier must be located in the same room with the humidostat.

The moistener or humidifier may be of any one of several forms. Where steam heating is used, and where the steam is clean and odorless and free from oil from engines, a perforated pipe (or pipes) in the air-duct is the simplest and best humidifier. The outlets are properly adjusted, and then the humidostat shuts off and lets on the steam as required. Sometimes a water spray, particularly of warm water, may be used in place of steam. When neither steam jet nor water spray is advisable, an evaporating pan containing a steam coil may be used, the humidostat controlling the steam to the coil, and the water-level in the pan being kept constant by means of a ball-cock.

AIR-FILTERS AND AIR-WASHERS

In cases where the air for ventilating purposes is likely to contain soot or street dust, it is desirable to provide some form of filter for purifying it before delivering to the rooms. If the air-quantity is small and there is plenty of room between the inlet windows and the fan, screens of light cheesecloth may be used for this purpose. The cloth should be tacked to light but substantial wooden frames, which can be easily removed for frequent cleaning. These screens are usually set up in "saw-tooth" fashion in order to give as much surface as possible in the least space.

Another arrangement, used in case of large volumes of air, is to provide a number of light cloth bags of considerable length, through which the air is drawn before reaching the heater. These are fastened to a suitable frame or partition for holding them open. The great objection to filters of this kind is their obstruction to the passage of the air, especially when filled with dust, the frequent intervals at which they should be cleaned, and the great amount of filtering surface required.

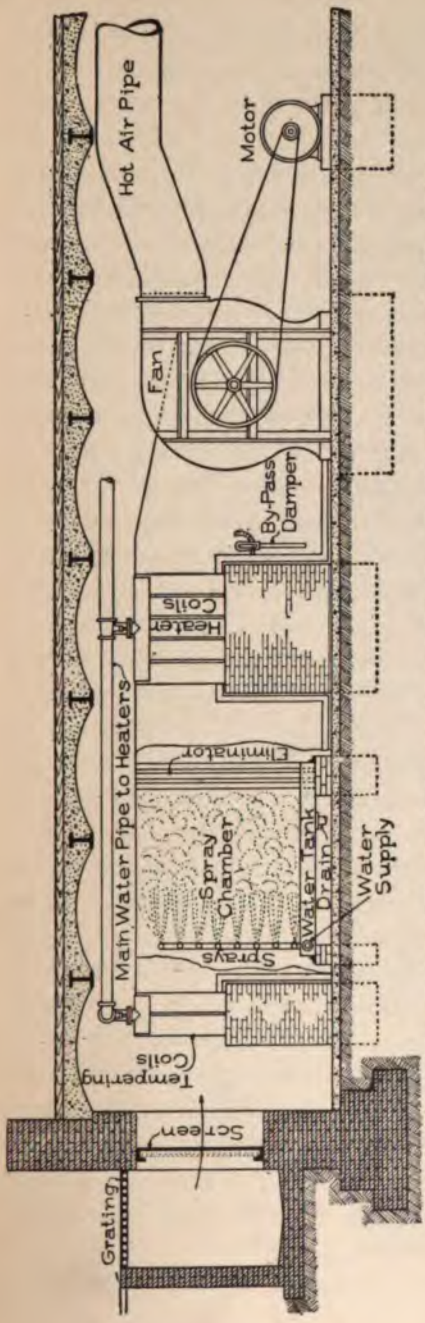

Fig. 172. One Form of Spray Filter or Air-Washer, for Removing Dust or Soot from Air Required for Ventilation.

An apparatus which is coming quite generally into use for this purpose, and which does away with the disadvantages noted above, is the *spray filter* or *air-washer*, one form of which is shown in Fig. 172. Air enters as indicated, and first passes through a tempering coil to raise it above the freezing point in winter weather; then passes through the spray-chamber, where the dirt is removed; then through an eliminator for removing the water; and then through a second heater on its way to the fan.

The water is forced through the spray-heads by means of a small centrifugal pump, either belted to the fan shaft or driven by an independent motor.

HEATING AND VENTILATION OF VARIOUS CLASSES OF BUILDINGS

The different methods used in heating and ventilation, together with the manner of computing the various proportions of the apparatus, having been taken up, the application of these systems to the different classes of buildings will now be considered briefly.

School Buildings. For school buildings of small size, the furnace system is simple, convenient, and generally effective. Its use is confined as a general rule to buildings having not more than six or eight rooms. For large ones this method must generally give way to some form of indirect steam system with one or more boilers, which occupy less space, and are more easily cared for than a number of furnaces scattered about in different parts of the basement. As in all systems that depend on natural circulation, the supply and removal of air is considerably affected by changes in the outside temperature and by winds.

The furnaces used are generally built of cast iron, this material being durable, and easily made to present large and effective heating surfaces. To adapt the larger sizes of house-heating furnaces to schools, a much larger space must be provided between the body and the casing, to permit a sufficient volume of air to pass to the rooms. The free area of the air-passage should be sufficient to allow a velocity of about 400 feet per minute.

The size of furnace is based on the amount of heat lost by radiation and conduction through walls and windows, *plus* that carried away by air passing up the ventilating flues. These quantities may be computed by the usual methods for "loss of heat by conduction through walls," and "heat required for ventilation." With more regular and skilful attendance, it is safe to assume a higher rate of combustion in schoolhouse heaters than in those used for warming residences. Allowing a maximum combustion of 6 pounds of coal per hour per square foot of grate, and assuming that 8,000 B. T. U. per pound are taken up by the air passing over the furnace, we have 6 × 8,000 = 48,000 B. T. U. furnished per hour per square foot of grate. Therefore, if we divide the total B. T. U. required for both warming and ventilation by 48,000, it will give us the necessary grate surface in square feet. It has been found in practice that a furnace with a firepot 32 inches in diameter, and having ample heating surface, is capable of heating two 50-pupil rooms in zero weather. The sizes of ducts and flues may be determined by rules already given under furnace and indirect steam heating.

The velocity of the warm air within the uptake flues depends upon their height and the difference in temperature between the warm air within the flues and the cold air outside. The action of the wind also affects the velocity of air-flow. It has been found by experience that flues having sectional areas of about 6 square feet for first-floor rooms, 5 square feet for the second floor, and 4½ square feet for the third, will be of ample size for standard classrooms seating from 40 to 50 pupils in primary and grammar schools. These sizes may be used for both furnace and indirect gravity steam heating.

The vent flues may be made 5 square feet for the first floor, and 6 square feet for the second and third floors. They may be arranged in banks, and carried through the roof in the form of large chimneys, or may be carried to the attic space and there gathered by means of galvanized-iron ducts connecting with roof vents of wood or copper construction.

In order to make the vent flues "draw" sufficiently in mild or heavy weather, it is necessary to provide some means for warming the air within them to a temperature somewhat above that of the rooms with which they connect. This may be done by placing a small stove made specially for the purpose, at the base of each flue. If this is done, it is necessary to carry the air down and connect with the flue just below the stove.

The cold-air supply duct to each furnace should be made ¾ the size of all the warm-air flues if free from bends, or the full size if obstructed in any way.

The inlet and outlet openings from the rooms into the flues, are commonly provided with grilles of iron wire having a mesh of 2 to 2½ inches. Both flat and square wire are used for this purpose. Mixing dampers for regulating the temperature of the rooms should be provided for each flue. The effectiveness of these dampers will depend largely upon their construction; and they should be made tight against cold-air leakage, by covering the surfaces or flanges against which they close with some form of asbestos felting. Both inlet and outlet gratings should be provided with adjustable dampers. One of the disadvantages of this system is the delivery of all the heat to the room from a single point, and this not always in a position to give the best results. The outer walls are thus left unwarmed, except as the heat is diffused throughout the room by air-currents. When there is considerable glass surface, as in most of our modern schoolrooms, draughts and currents of cold air are frequently found along the outside walls.

The indirect gravity system of steam heating comes next in cost of installation. One important advantage of this system over furnace heating comes from the ability to place the heating coils at the base of the flues, thus doing away with horizontal runs of air-pipe, which are required to some extent in furnace heating. The warm-air currents in the flues are less affected by variations in the direction and force of the wind where this construction is possible, and this is of much importance in exposed locations.

The method of supplying cold air to the coils or heaters is important, and should be carefully worked out. The supply should be taken from at least two sides of the building, or, if possible, from all four sides. When it is taken from four sides, each inlet should be made large enough to supply one-half the amount, or, in other words, any two should give the total quantity required. It is often possible to arrange the flues in groups so that all the heating stacks may be placed in two or more cold-air chambers, depending upon the size of the building. A cold-air trunk line may be run through the center of the basement, connecting with the outside on all four sides, and having branches supplying each cold-air chamber.

Cast-iron pin-radiators are particularly adapted to this class of work.

The *School-Pin*, having a section about 10 inches in depth and rated at 15 square feet of heating surface per section, is used quite extensively for this purpose. Stacks containing about 240 square feet of surface for southerly rooms, and 260 for those having a northerly exposure, have been found ample for ordinary conditions in zero weather.

A very satisfactory arrangement is the use of indirect heaters for warming the air needed for ventilation, and the placing of direct radiation in the rooms for heating purposes. The general construction of the indirect stacks and flues may be the same; but the heating surface can be reduced, as the air in this case must be raised only to 70 or 75 degrees in zero weather, the heat to offset that lost by conduction, etc., through walls and windows being provided by the direct surface. The mixing dampers may be omitted, and the temperature of the room regulated by opening or closing the steam valves on the direct coils, which should be done automatically. The direct-heating surface, which is best made up of lines of 1¼-inch pipe, should be placed along the outer walls beneath the windows This supplies heat where most needed, and does away with the tendency to draughts. In mild weather, during the spring and fall, the indirect heaters may prove sufficient for both ventilation and warming.

Where direct radiation is placed in the rooms, the quantity of heat supplied is not affected by varying wind conditions, as is the case in indirect heating. Although the air-supply may be reduced at times, the heat quantity is not changed. Direct radiation has the disadvantage of a more or less unsightly appearance, and architects and owners often object to the running of mains or risers through the rooms of the building. Air-valves should always be provided with drip connections carried to a sink or dry well in the basement.

When circulation coils are used, a good method of drainage is to carry separate returns from each coil to the basement, and to place the air-valves in the drops just below the basement ceiling. A check-valve should be placed below the water-line in each return.

The gravity system has the fault of not supplying a uniform quantity of air under all conditions of outside temperature, the same as a furnace, but when properly arranged, may be made to give quite satisfactory results.

The fan or blower system for ventilation, with direct radiation in the rooms for warming, is considered to be one of the best possible arrangements.

In designing a plant of this kind, the main heating coil should be of sufficient size to warm the total air-supply to 70 or 75 degrees in the coldest weather, and the direct surface should be proportioned for heating the building independently of the indirect system. Automatic temperature regulation should be used in connection with systems of this kind, by placing pneumatic valves on the direct radiation. It is customary to carry from 3 to 8 pounds pressure on the direct system, and from 8 to 15 pounds on the main coil, depending upon the outside temperature. The foot-warmers, vestibule, and office heaters should be placed on a separate line of piping, with separate returns and trap, so that they can be used independently of the rest of the building if desired. Where there is a large assembly hall, it should be arranged so that it can be both warmed and ventilated when the rest of the building is shut off. This can be done by a proper arrangement of valves and dampers.

When different parts of the system are run on different pressures, the returns from each should discharge through separate traps into a receiver having connection with the atmosphere by means of a vent pipe. Fig. 173 shows a common arrangement for the return connections in a combination system of this kind. The different traps discharge into the vented receiver as shown; and the water is pumped back to the boiler automatically when it rises above a given level in the receiver, a pump governor being used to start and stop the pumps as required.

A water-level or seal of suitable height is maintained in the main returns, by placing the trap at the required elevation and bringing the returns into it near the bottom; a balance pipe is connected with the top for equalizing the pressure, the same as in the case of a pump governor. Sometimes a fan is used with the heating coils placed at the base of the flues, instead of in the rooms. Where this is done the radiating surface may be reduced about one-half. This system is less expensive to install, but has the disadvantage of removing the heating surface from the cold walls, where it is most needed.

With a blower type of fan, the size of the main ducts may be based on a velocity of from 1,000 to 1,200 feet per minute, and the branches on a velocity of 800 to 1,000 feet per minute.

The velocity in the vertical flues may be from 600 to 700 feet per minute, although the lower velocity is preferable.

The size of the inlet registers should be such that the velocity of the entering air will not exceed 350 to 400 feet per minute.

When the air is delivered through a register at the high velocities mentioned, some means must be provided for diffusing the entering current, in order to prevent disagreeable draughts. This is usually accomplished by the use of deflecting blades of galvanized iron, set in a vertical position and at varying angles, so that the air is thrown towards each side as it issues from the register. The size of the vent flues should be about the same as for a gravity system—that is, about 6 square feet for a standard classroom, and in the same proportion for smaller rooms.

Vent-flue heaters are not usually required in connection with a fan system, as the force of the fan is sufficient to supply the required

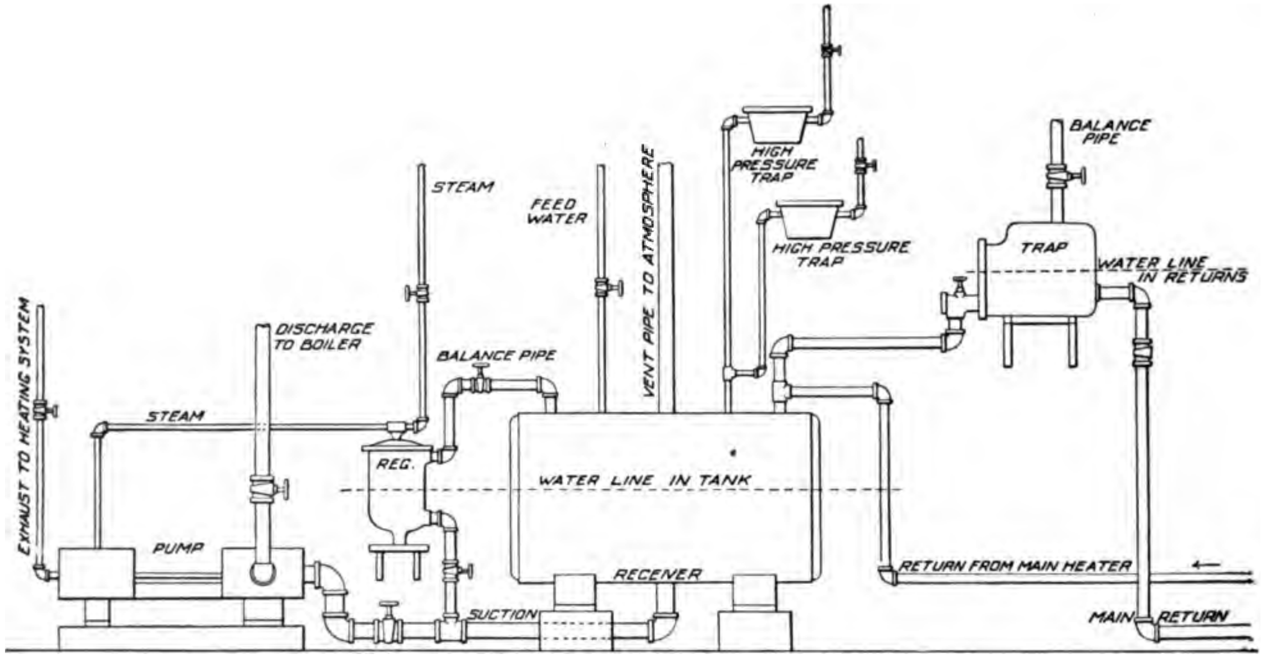

Fig. 173. General Arrangement of Return Connections Especially Adapted to Large Buildings where Different Parts of the Heating System are under Different Pressures.

quantity of air at all times without the aspirating effect of the vent flues.

The method of piping shown in Fig. 173 applies especially to buildings of large size. In the case of medium-sized buildings, it is often possible to use pin radiation for the main heater, placing the same well above the water-line of the boilers and thus returning the condensation by gravity, without the use of pumps or traps. When this arrangement is used, an engine with a large cylinder should be employed, so that the steam pressure will not exceed 15 or 18 pounds, and the whole system, including the direct surface, may be run upon the same system.

This is a very simple arrangement, and is adapted to all buildings of small and medium size where the heater can be placed at a sufficient height above the boilers.

Temperature control is usually secured automatically by placing pneumatic valves upon either the direct or supplementary heaters. Mixing dampers are sometimes used instead, in the latter case. Every fan system should be provided with a thermometer of large size for indicating the temperature of the air in the main duct just beyond the fan.

The ventilation of the toilet-rooms of a school building is a matter of the greatest importance. The first requirement is that the air-movement shall be *into* these rooms from the corridors instead of outward. To obtain this result, it is necessary to produce a slight vacuum within, and this cannot well be done if fresh air is forced into them.

One of the most satisfactory arrangements is to provide exhaust ventilation only, and to remove the greater part of the air through local vents connecting with the fixtures.

Hospitals. The best system for heating and ventilating a hospital depends upon the character and arrangement of the buildings. It is desirable in all cases to do the heating from a central plant, rather than to carry fires in the separate buildings, both on account of economy and for cleanliness.

In the case of small cottage hospitals with two or three buildings placed close together, indirect hot water affords a desirable system for the wards, with direct heat for the other rooms; but where there are several buildings, and especially if they are some distance apart, it becomes necessary to substitute steam unless the water is pumped through the mains. For large city buildings, a fan system is always desirable.

If the building is tall compared with its ground area, so that the horizontal supply ducts will be comparatively short, the double-duct system may be used with good results. Where the rooms are of good size, and the number of supply flues not great, the use of supplementary heaters at the bases of the flues makes a satisfactory arrangement. Direct radiation should never be used in the wards when it can be avoided, even in connection with an independent air-supply, as it offers too great an opportunity for the accumulation of dust in places which are difficult to reach.

It is common to provide from 80 to 100 cubic feet of air per minute per patient in ordinary wards, and from 100 to 120 cubic feet in contagious wards.

The usual ward building of a modern cottage-hospital generally contains a main ward having from 8 to 12 beds, and a number of private rooms of one bed each.

In addition to these, there are a diet kitchen, duty-room, toilet-rooms, bathrooms, linen-closets, and lockers.

For moderately sheltered locations, 30 square feet of indirect steam radiation has been found sufficient in zero weather for a single ward with one exposed wall and a single window, when upon the south side of the building.

For northerly rooms, 40 square feet should be used. In exposed locations, the heaters may be made 40 and 50 square feet for north and south rooms respectively. The standard pin-radiators rated at 10 square feet of heating surface per section, are commonly used for this purpose. In case hot water is used, the same number of sections of the deep-pin pattern rated at 15 square feet each may be employed, making a total of 45 and 60 square feet per room. For corner rooms having two exposed walls and two windows, the amount of radiation should be increased about 50 per cent over that given above.

The wards are usually furnished with fireplaces which provide for the discharge ventilation. In case the fireplaces are omitted, a special vent flue, either of brick or of galvanized iron, should be provided. These should not be less than 8 by 12 inches for single wards, and the equivalent for each bed in a large ward. Each flue of this kind should have a loop of steam pipe for producing a draught. A loop of 1-inch pipe, 10 or 12 feet in height, is usually sufficient for this purpose.

Other rooms than wards are usually heated with direct radiators, the sizes of which may be computed in the same manner as for dwelling-houses.

Steam tables for the kitchen, sterilizers, and laundry machinery, require higher pressures than is necessary for heating.

In large plants the boilers are usually run at high pressure, and the pressure reduced for heating. A good arrangement for small plants is to provide sufficient boiler power for warming and ventilating purposes, and run at a pressure of 3 to 5 pounds. In addition to this, a small high-pressure boiler carrying 70 or 80 pounds should be furnished for laundry work and water heating.

Churches. Churches may be warmed by furnaces, by indirect steam, or by means of a fan. For small buildings the furnace is more commonly used. This apparatus is the simplest of all and is comparatively inexpensive. Heat may be generated quickly, and when the fires are no longer needed, they may be allowed to go out without danger of damage to any part of the system from freezing.

It is not usually necessary that the heating apparatus be large enough to warm the entire building at one time to 70 degrees with frequent change of air. If the building is thoroughly warmed before occupancy, either by rotation or by a slow inward movement of outside air, the chapel or Sunday-school room may be shut off until near the close of the service in the auditorium, when a portion of the warm air may be turned into it. When the service ends, the switch-damper is opened wide, and all the air is discharged into the Sunday-school room. The position of the warm-air registers will depend somewhat upon the construction of the building, but it is well to keep them near the outer walls and the colder parts of the room. Large inlet registers should be placed in the floor near the entrance doors, to stop cold draughts from blowing up the aisles when the doors are opened, and also to be used as foot-warmers.

Ceiling ventilators are generally provided, but should be no larger than is necessary to remove the products of combustion from the gaslights, etc. If too large, much of the warmest and purest air will escape through them. The main vent flues should be placed in or near the floor and should be connected with a vent shaft leading outboard. This flue should be provided with a small stove or flue heater made specially for this purpose. In cold weather the natural draught will be found sufficient in most cases.

The same general rules are to be followed in the case of indirect steam as have been described for furnace heating. The stacks are placed beneath the registers or flues, and mixing dampers provided. If there are large windows, flues should be arranged to open in the window-sills, so that a sheet of warm air may be delivered in front of the windows, to counteract the effects of cold down-draughts from the exposed glass. These flues may usually be made 3 or 4 inches in depth, and should extend the entire width of the window. Small rooms, such as vestibules, library, pastor's room, etc., are usually heated with direct radiators. Rooms which are used during the week are often connected with an independent heater so that they may be warmed without running the large boilers, as would otherwise be necessary.

When a fan is used, it is desirable, if possible, to deliver the air to the auditorium through a large number of small openings. This is often done by constructing a shallow box under each pew, running its entire length, and connecting it with the distributing ducts or a plenum space by means of a pipe from below. The air is delivered at a low velocity through a long slot, as shown in Fig. 174.

The warm-air flues in the window-sills should be retained, but may be made shallower, and the air forced in at a high velocity.

If the auditorium has a sloping floor, a plenum space may be provided between the upper or raised portion and the main floor. Sometimes a shallow basement 3 or 4 feet in height, with a cemented floor, and extending under the entire auditorium, is used as an air or plenum space.

If the basement is of good height and used for storage or other purposes, it is necessary to carry galvanized-iron ducts at the ceiling under the center of each double row of pews, and to connect with each pair by means of branch uptakes. The size of these should be equal to 3 or 4 square inches for each occupant.

Another method is to supply the air through a small register in the end of each pew. This simplifies the pew construction somewhat, but otherwise is not so satisfactory as the preceding method.

If the special pew construction is too expensive, or for any other reason cannot well be used, and the fan is to be retained, the greater part of the air is best introduced through wall registers placed about 8 feet above the floor, with exhaust openings at or near the floor. By this arrangement the air is thrown horizontally toward the center of the church, and much of it falls to the breathing level without rising to the upper part of the room.

Halls. The treatment of a large audience hall is similar to that of a church, the warming being usually done in one of the three ways already described. Where a fan is used, the air is commonly delivered through wall registers placed in part near the floor, and partly at a height of 7 or 8 feet above it. They should be made of ample size, so that there will be freedom from draughts. A part of the vents should be placed in the ceiling, and the remainder near the floor. All ceiling vents, in both halls and churches, should be provided with dampers having means for holding them in any desired position. If indirect gravity heaters are used, it will generally be necessary to place heating coils in the vent flues for use in mild weather; but if the fresh air is supplied by means of a fan, there will usually be pressure enough in the room to force the air out without the aid of other means. When the vent air-ways are restricted, or the air is impeded in any way, electric ventilating fans are often used. These give especially good results in warmer weather, when natural ventilation is sluggish. The temperature may be regulated either by using the double-duct system or by shutting off or turning on a greater or less number of sections in the main heater. After an audience hall is once warmed and filled with people, very little heat is required to keep it comfortable, even in the coldest weather.

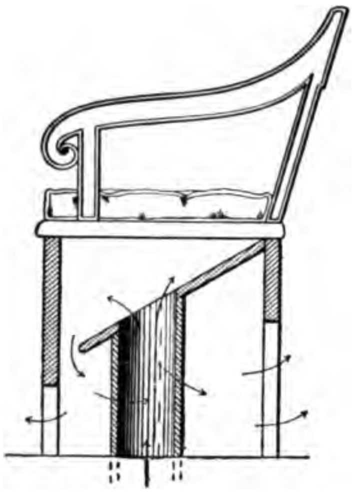

Fig. 174. An Approved Method of Delivering Warm Air to the Auditorium of a Church.

Theaters. In designing heating and ventilating systems for theaters, a wide experience and the greatest care are necessary to secure the best results. A theater consists of three parts: the body of the house, or auditorium; the stage and dressing-rooms, and the foyer, lobbies, corridors, stairways, and offices. Theaters are usually located in cities, and surrounded with other buildings on two or more sides, thus allowing no direct connection by windows with the external air; for this reason artificial means are necessary for providing suitable ventilation, and a forced circulation by means of a fan is the only satisfactory means of accomplishing this. It is usually advisable to create a slight excess of pressure in the auditorium, in order that all openings shall allow for the discharge rather than the inward leakage of air.

The general and most approved method of air-distribution is to force it into closed spaces beneath the auditorium and balcony floors, and allow it to discharge upward through small openings among the seats. One of the best methods is through chair-legs of special latticed design, which are placed over suitable openings in the floor; in this way the air is delivered to the room in small streams, at a low velocity, without draughts or currents. The discharge ventilation should be largely through ceiling vents, and this may be assisted if necessary by the use of ventilating fans. Vent openings should also be provided at the rear of the balconies, either in the wall or in the ceiling, and these should be connected with an exhaust fan either in the basement or in the attic, as is most convenient.

The close seating of the occupants produces a large amount of animal heat, which usually increases the temperature from 6 to 10 degrees, or even more; so that, in considering a theater once filled and thoroughly warmed, it becomes more of a question of cooling than one of warming to produce comfort.

The dressing-rooms should be provided with a generous supply of fresh air, sufficient to change the entire contents once in 10 minutes at least, and should have discharge flues of sufficient size to carry away this amount of air at a velocity not exceeding 300 feet per minute, unless connected with an exhaust fan, in which case the velocity may be doubled. The foyer, corridors, dressing-rooms, etc., are generally heated by direct radiators, which may be concealed by ornamental screens if desired.

Office Buildings. This class of buildings may be satisfactorily warmed by direct steam, hot water, or, where ventilation is desired, by the fan system. Probably direct steam is used more frequently than any other system for this purpose. Vacuum systems are well adapted to the conditions usually found in this type of building, as most modern office buildings have their own light and power plants, and the exhaust steam can thus be utilized for heating purposes. The piping may be either single or double. If the former is used, it is better to carry a single main riser to the upper story, and run drops to the basement, as by this means the steam and water flow in the same direction, and much smaller pipes can be used than would be the case if risers were carried from the basement upward.

Special provision must be made for the expansion of the risers or drops in tall buildings. They are usually anchored at the center, and allowed to expand in both directions. The connections with the radiators must not be so rigid as to cause undue strains or to lift the radiators from the floor.

It is customary, in most cases, to make the connections with the end farthest from the riser; this gives a length of horizontal pipe which has a certain amount of spring, and will care for any vertical movement of the riser that is likely to occur. Forced hot-water circulation is often used in connection with exhaust steam. The water is warmed by the steam in large heaters similar to feed-water heaters and is circulated through the system by means of centrifugal pumps. This has the usual advantage of hot water over steam, inasmuch as the temperature of the radiators may be regulated to suit the conditions of outside temperature.

When a fan system is used the arrangement of the air-ways is usually somewhat different from any of those yet described. Owing to the great height of these buildings, and the large number of small rooms which they contain, it is impossible to carry up separate flues from the basement. One of the best arrangements is to construct false ceilings in the corridor-ways on each floor, thus forming air-ducts which may receive their supply through one or more large uptakes extending from the basement to the top of the building. These corridor air-ways may be tapped over the door of each room, the openings being provided with suitable regulating dampers for gauging the air-supply to each. Adjustable deflectors should be placed in the main air-shafts for proportioning the quantity to be delivered to each floor. If both supply and discharge ventilation are to be provided, the fresh air may be carried in galvanized-iron ducts within the ceiling spaces, and the remainder used for conveying the exhausted air to uptakes leading to a discharge fan placed upon the roof of the building. In both of these cases, it is assumed that heat is supplied to the rooms by direct radiation, and that the air-supply is for ventilation only.

Apartment Houses. These are warmed by furnaces, direct steam, and hot water. Furnaces are more often used in the smaller houses, as they are cheaper to install, and require a less skilful attendant to operate them. Steam is probably used more than any other system in blocks of larger size. A well-designed single-pipe connection, with automatic air-valves dripped to the basement, is probably the most satisfactory in this class of work. People who are more or less unfamiliar with steam systems are apt to overlook one of the valves in shutting off or turning on steam; and where only one valve is used, the difficulty arising from this is avoided. Where pet-cock air-valves are used, they are often left open through carelessness; and the automatic valves, unless dripped, are likely to give more or less trouble.

Greenhouses and Conservatories. Buildings of this class are heated in some cases by steam and in others by hot water, some florists preferring one and some the other. Either system, when properly designed and constructed, should give satisfaction, although hot water has its usual advantage of a variable temperature. The methods of piping are, in a general way, like those already described, and the pipes may be located to run underneath the beds of growing plants or above, as bottom or top heat is desired. The main is generally run near the upper part of the greenhouse and to the farthest extremity, in one or more branches, with a pitch upward from the heater for hot water and with a pitch downward for steam. The principal radiating surface is made of parallel lines of 1½ inch or larger pipe, placed under the benches and supplied by the return current. Figs. 175, 176, and 177 show a common method of running the piping in greenhouse work. Fig. 175 shows a plan and elevation of the building with its lines of pipe; and Figs. 176 and 177 give details of the pipe connections of the outer and inner groups of pipes respectively.

Any system of piping which gives free circulation and which is adapted to the local conditions, should give satisfactory results. The radiating surface may be computed from the rules already given. As the average greenhouse is composed almost entirely of glass, we

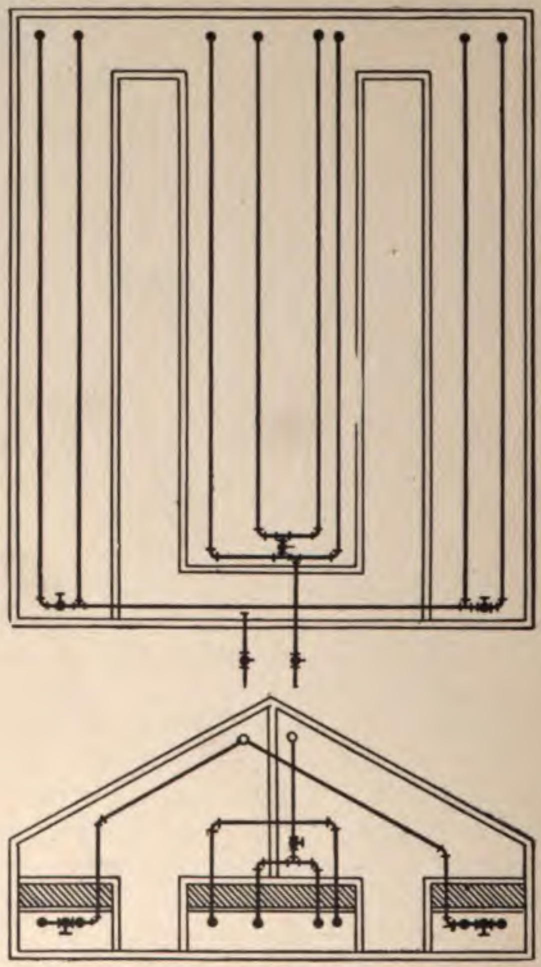

Fig. 175. Plan and Elevation Showing One Method of Running Piping in a Greenhouse

may for purposes of calculation consider it such; and if we divide the total exposed surface by 4, we shall get practically the same result as if we assumed a heat loss of 85 B. T. U. per square foot of surface per hour, and an efficiency of 330 B. T. U. for the heating coils; so that we may say, in general, that the square feet of radiating surface required equals the total exposed surface, divided by 4 for steam coils, and by 2.5 for hot-water. These results should be increased from 10 to 20 per cent for exposed locations.

CARE AND MANAGEMENT

The care of furnaces, hot-water heaters, and steam boilers has been discussed in connection with the design of these different systems of heating, and need not be repeated. The management of the heating and ventilating systems in large school buildings is a matter of much importance, especially in those using a fan system. To obtain the best results, as much depends upon the skill of the operating engineer as upon that of the designer.

Beginning in the boiler-room, he should exercise special care in the management of his fires, and the instruction given in "Boiler Accessories" should be carefully followed; all flues and smoke passages should be kept clear and free from accumulations of soot and ashes by means of a brush or steam jet. Pumps and engine should be kept clean and in perfect adjustment, and extra care should be taken when they are in rooms through which the air-supply is drawn, or the odor of oil will be carried to the rooms. All steam traps should be examined at regular intervals to see that they are in working order; and upon any sign of trouble, they should be taken apart and carefully cleaned.

The air-valves on all direct and indirect radiators should be inspected often; and upon the failure of any room to heat properly, the air-valve should first be looked to as a probable cause of the difficulty. Adjusting dampers should be placed in the base of each flue, so that the flow to each room may be regulated independently. In starting up a new plant, the system should be put in proper balance by a suitable adjustment of these dampers; and, when once adjusted, they should be marked, and left in these positions. The temperature of the rooms should never be regulated by closing the inlet registers. These should never be touched unless the room is to be unused for a day or more.

In designing a fan system, provision should be made for *air-rotation*; that is, the arrangement should be such that the same air may be taken from the building and passed through the fan and

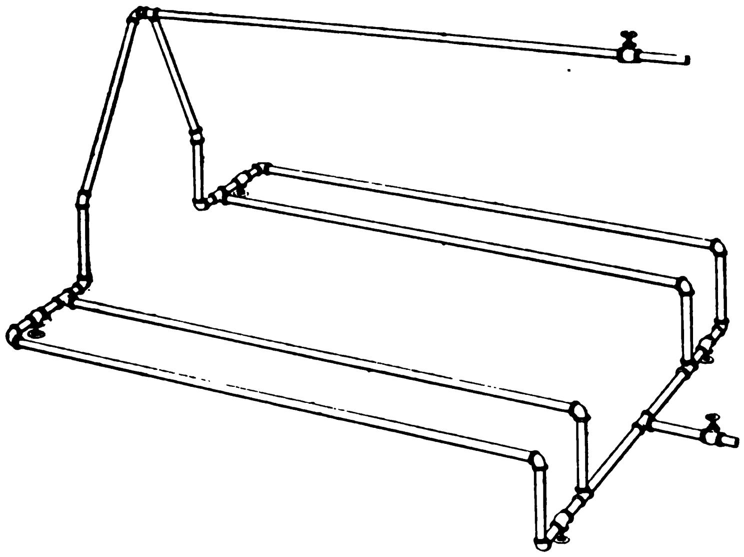

Fig. 176. Connections of Outer Groups of Pipes of Greenhouse Shown in Fig. 175.

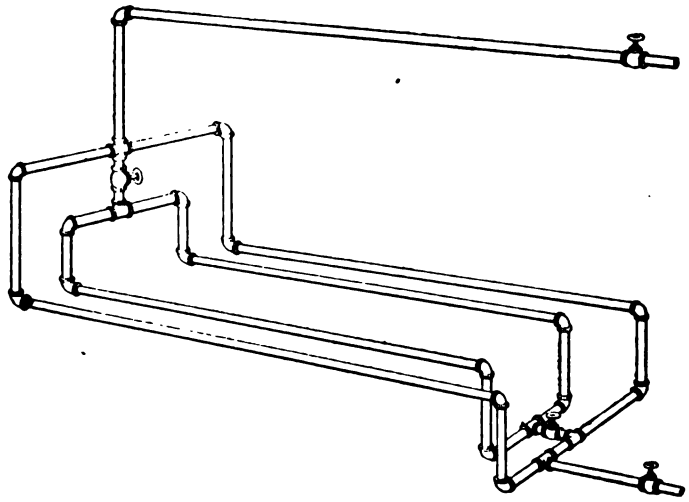

Fig. 177. Connections of Inner Groups of Pipes of Greenhouse Shown in Fig. 175.

heater continuously. This is usually accomplished by closing the main vent flues and the cold-air inlet to the building, then opening the class-room doors into the corridor-ways, and drawing the air down the stair-wells to the basement and into the space back of the main heater through doors provided for this purpose. In warming up a building in the morning, this should always be done until about fifteen minutes before school opens. The vent flues should then be opened, doors into corridors closed, cold-air inlets opened wide, and the full volume of fresh air taken from out of doors.

At night time the dampers in the main vents should be closed, to prevent the warm air contained in the building from escaping. The fresh air should be delivered to the rooms at a temperature of from 70 to 75 degrees; and this temperature must be obtained by proper use of the shut-off valves, thus running a greater or less number of sections on the main heater. A little experience will show the engineer how many sections to carry for different degrees of outside temperature. A dial thermometer should be placed in the main warm-air duct near the fan, so that the temperature of the air delivered to the rooms can be easily noted.

The exhaust steam from the engine and pumps should be turned into the main heater; this will supply a greater number of sections in mild weather than in cold, owing to the less rapid condensation.

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